THE 'BOYS' OWN BOOK OF GREAT INVENTIONS

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PREFACE

The purpose of this book is to tell the story of some few of the great epoch-making inventions, to trace their influence upon world progress and to describe, so far as possible, simple experiments, embodying the principles involved, for home laboratory work. Many very important inventions and discoveries have had to be omitted. The field to be covered is so broad and the limits of a single book so narrow that the selection of subject-matter has been of necessity largely a process of judicious elimination. But in a book of this sort it is not so important what particular subjects are discussed as it is to teach certain fundamental truths and to emphasize the tremendous influence upon human affairs of the so-called dreamer, the man of vision, who in spite of every obstacle of fate and man has blazed the path of progress for the race. We cannot point out too often that genius is very frequently but another name for imagination. The inventor and the poet are in spirit one. The poet creates a mental image and clothes it in words suggestive of the thought picture. The inventor conceives the idea of an instrument, fraught with great material possibilities, and embodies it in a suitable mechanism. Both the poem and the machine, as everything else in the universe, are mental creations. The most intricate piece of machinery existed in the mind of the inventor before it could be translated into visible and tangible form. But in every instance the thinking of the inventor must be true to the eternal laws of the universe if his creation is

to have meaning and purpose in it. The inventor's mind is a mirror of universal truths and if his thinking does not reflect them as they are, the product is distortion, error and failure. Some few great minds have caught the vision of a small portion of the truths of Nature and have materialized them for the benefit of mankind. But there is still an ocean of almost infinite possibility for the inventor. The age of discovery and achievement has only just begun and we may be perfectly sure that, so long as the race is here, there will yet be progress to make. Surely the miracles of Science have not all been wrought.

The writer is under obligation to a large number of business organizations for their kindness in supplying photographs and material used in the preparation of the book. He wishes especially to acknowledge his indebtedness to his wife for making more than two-thirds of the drawings for the line cuts and for typing the manuscript. Credit is also due to Miss Beatrice Booraem for a part of the drawings used in the cuts.

FLOYD L. DARROW.

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CHAPTER I

THE GYRO PARADOX

WE are all acquainted with the spinning top vender who, on the crowded street corner, at the automobile show or country fair, displays his wares and demonstrates to a curious and credulous group how his uncanny gyros utterly defy the law of gravity, and tells you that no scientist wise enough to explain their action has yet appeared.

But gyroscopic action is as old as the universe itself Do you know that the earth beneath your feet is a huge gyroscope ceaselessly obeying the same laws as the spinning top? The rolling hoop which as a child led you many a merry chase owes its balancing power to these self-same laws. At once the plaything of children and the marvel of sages, who of us little more than a decade ago would have imagined that within this toy lay hidden the possibilities of the mono-rail car, a gyro-compass of absolute reliability and infinitely more accurate than the magnetic, an automatic aeroplane stabilizer, a means of steadying a ship in the roughest sea, a steering device for the torpedo and perfect proof of the earth's rotation? Do you realize that the wonderful stability of your wheel or motorcycle is due solely to the principle of the spinning top and that it is the gyroscopic action of a swiftly rotating bullet that carries

it straight to the mark? Do you know, too, that the pole star of to-day is not the pole star of ten thousand years ago nor will it continue to be the pole star of the future? And this because of the gyroscopic movement of the earth as it spins on its axis and at the same time whirls about the sun.

Far from being a puzzle the gyroscope admits of both mathematical and popular explanation. Its marvelous balancing power is one of the most striking illustrations of the fundamental law of inertia, the most common property of all matter. Inertia means inactivity. A body at rest tends to remain at rest or if in motion to continue in motion unless acted upon by an outside force. This is a matter of common experience. As we endeavor to keep our balance in a swiftly moving subway train with its sudden changes of motion and bending about sharp curves, we get a very vivid realization of the opposition which a body offers to any change in its state of rest or motion. The distance to which the athlete throws the discus is determined by the quantity of inertia which he can store up in it as he whirls the circular plate about his head. When he throws it, too, he simply lets go and the inertia of the moving discus carries it off in a straight line tangent to the curve in which it moves. The inertia stored up in a massive flywheel keeps the machinery running smoothly and without vibration. A moving train does not stop when the power is turned off but only when the brakes have been applied and the friction and air resistance have overcome its momentum, and momentum is simply the inertia of a moving body. The earth rotates on its axis and revolves around the sun with no change in its velocity because it meets with no resistance and is itself powerless to accelerate or retard its motion. Its inertia keeps it going. So with our top, or gyroscope. When set spinning it resists with a force, altogether greater

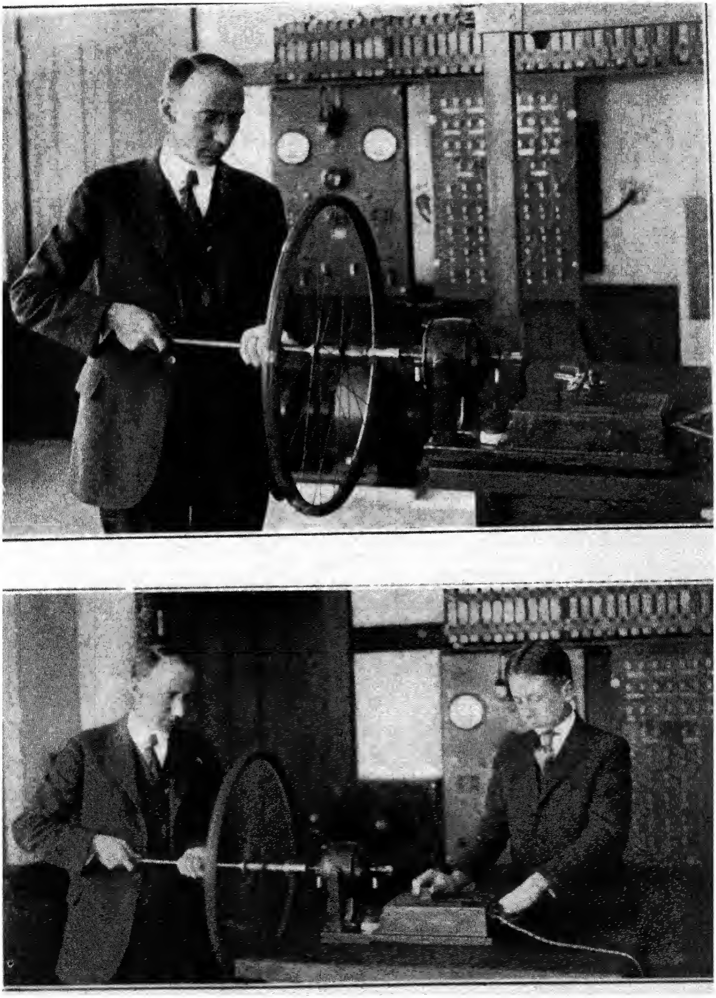
than would be expected from its size and weight, any tendency to change its plane of rotation, or the direction in which its axis points. This is simply the inertia of a rotating body and its magnitude depends upon the mass and speed of the body. The swiftly turning wheels of a motorcycle resist with a tremendous force any change in their plane of rotation and therefore balance themselves and rider in perfect security.

To better study the laws of rotating bodies I made a gyroscope from a bicycle wheel and operated it with an electric motor. On one side of the hub I brazed a clutch similar to that of an automobile crank. I extended the cone shaft about two and one-half feet by boring and threading a hole in the end of a steel rod and screwing this onto the projecting end of the shaft. This was made secure with a set-screw. About midway of the bar a socket was bored to provide for mounting the spinning wheel upon the upright support. A chuck and holder to fit the end of the motor shaft were provided so as to engage the clutch in speeding up the gyroscope. I weighted the rim with a large number of turns of copper wire, holding it in place with copper bands, and trued the wheel about the shaft perfectly with small quantities of solder placed wherever needed on the rim. The heavier the rim the less will be the speed required, but a fellow experimenter in using lead for this purpose found that as he speeded up the wheel the lead began to leave the rim and he very prudently began to leave the room.

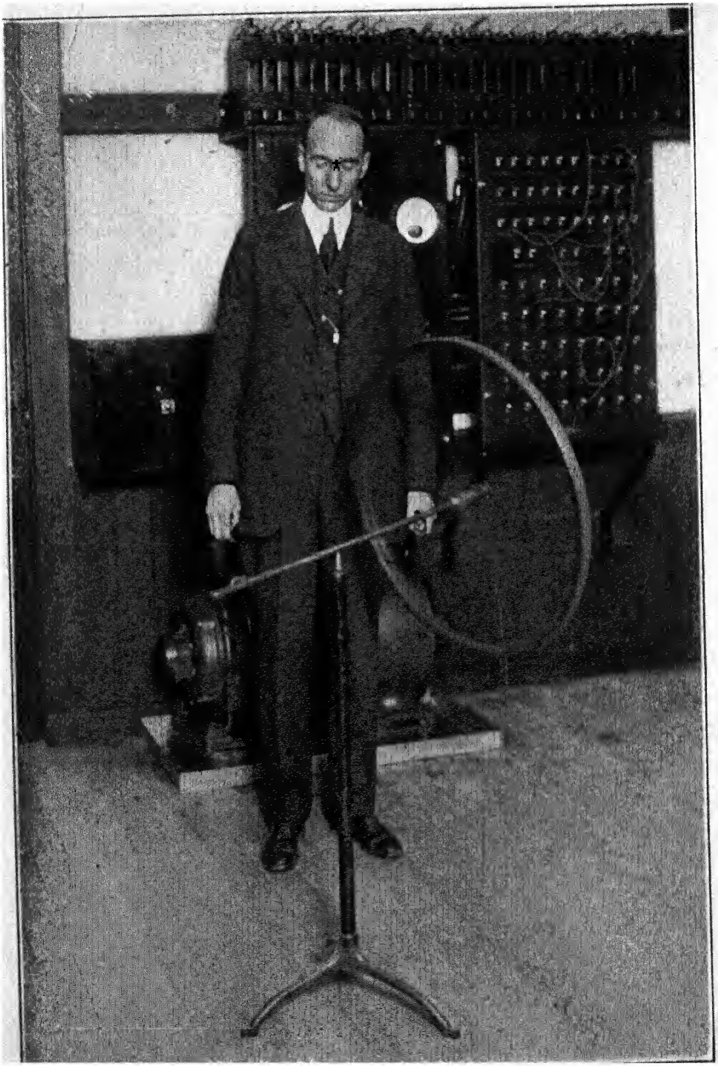
In making a demonstration the operator holds the clutch of the gyroscope firmly against the chuck on the end of the motor shaft and his assistant gradually speeds up the motor. When a fairly high speed has been attained the gyroscope is withdrawn and mounted upon the support as shown in

the cut. Instead of falling, however, the end of the shaft bearing the wheel stands slightly above the horizontal and the gyroscope at once begins to revolve, or "precess" about the vertical support, seeming to the popular mind completely to defy the law of gravity. As the speed of the wheel dies down its axis slowly drops to the horizontal, then below and gradually the action ceases. If the wheel be operated in the opposite direction the same phenomenon occurs except that the precession is also in the opposite direction. Holding the rapidly rotating gyroscope in the hands one experiences no difficulty in moving it in any direction so long as the plane of rotation is not changed. But attempt to disturb this and a tremendous resistance at once develops. One seemingly wrestles with a giant. We are opposing the inertia of a rotating body and find that it is very great. Once set spinning in a certain plane our gyroscope continues to rotate in that plane with all the momentum it possesses.

But why does the gyroscope precess? Why does it not fall? Far from being in defiance of the law of gravity it is on the contrary because of this law that the gyroscope behaves as it does. A body that is under the influence of two forces or two motions at the same time can never act as though it were under the influence of only one. And this is just what the popular mind does not take into account. Our gyroscope is made to rotate about one axis and it will be readily apparent that the gravitation of the earth tends to rotate it about another axis at right angles to the first. Therefore the gyroscope can rotate about neither axis as though the other rotation were absent, but must tend to rotate about an axis lying between the two. In trying to place itself parallel with this intermediate axis the gyroscope begins to revolve, or precess as it is called, but in so doing



Speeding up the gyroscope.



Demonstrating the precessional movement of the gyroscope.

the direction of each axis shifts, and so long as the speed of the gyroscope keeps up its own axis will continually chase this intermediate axis about the vertical support but never catch up with it. Were there no gravitational force our gyroscope would rotate with its axis at right angles to the support but there would be no precession. This is conclusively shown by placing a counterpoise on the free arm of the gyroscope shaft just sufficient to balance the weight of the wheel when the precession immediately ceases. Thus when the force of gravity is neutralized the gyroscopic action disappears. If the counterpoise is moved to the end of the shaft causing the wheel to move upward, precession at once begins again but is in the opposite direction. After such a demonstration even the most skeptical could never assert that the gyroscope suspends the law of gravity.

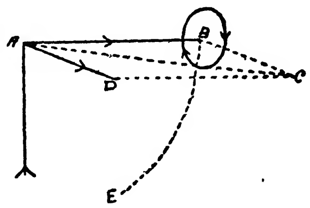


FIG. 1.—In the above diagram the wheel is rotating about axis AB and at the same time the force of gravity is tending to pull it downward along arc BE and about axis AD. Therefore the wheel being under the influence of two curvilinear motions tends to move forward so that its axis of rotation will coincide with the intermediate axis AC and in so doing begins to "precess." As the wheel precesses, however, both axes AB and AD also move forward and with them axis AC thus causing the precessional movement to continue so long as the wheel continues to rotate.

The earth itself affords one of the most perfect examples of gyroscopic action. Because of the earth's constant rotation its axis with slight variation points in the same direction from century to century. It is simply a spinning top. At the same time that it rotates on its axis, however, it is re-

volving around another axis in its annual movement about the sun. The two axes are inclined at an angle of 23½ degrees to each other and therefore just as our gyroscope precesses so does the earth. It is continually endeavoring to place its axis parallel to the axis of its orbit but with no better success than the gyroscope. But the precessional movement which results, constantly shifts westward the equinotial points, where the sun crosses the equator, at the rate of 55 seconds of arc each year and causes the axis of the earth to describe a small circle in the heavens completing it once each cycle of 25,900 years. In other words the earth wobbles just as a top does in dying down. This accounts for the former statement that the pole star is not constant.

One of the more recent and probably the most important application of the gyroscope is in the gyro-compass. This compass is now a part of the equipment of all modern battleships and submarines in the various navies of the world and it is a matter of no little pride to Americans that an American inventor, Mr. Elmer A. Sperry of Brooklyn, has contributed most toward the perfection of this marvelous piece of mechanism.

In order to understand the action of the gyro-compass suppose we carry a gyroscope, mounted similarly to the one shown in the cut, to the North Pole. Such a gyroscope has three degrees of freedom, that is, it rotates upon one axis and is free to turn about two others, one horizontal and at right angles to the first and the other vertical. Suppose now that we clamp the gyroscope in a horizontal plane allowing it to turn only about the vertical axis and then set it spinning. If by means of electricity we keep up the spin the axis of the gyroscope will point constantly in the same direction but, because of the rotation of the

earth beneath it, this axis will seem to turn successively to every point of the compass and describe a complete circle every twenty-four hours. Thus does the gyroscope prove the earth's rotation.

Now suppose we make a larger and heavier gyroscope mounted with three degrees of freedom and operated by electricity. Let us as before clamp the gyroscope in a horizontal plane but give it freedom about the vertical axis and then set it spinning. Now since the gyroscope is under the influence of two motions, its own rotation and the rotation of the earth, it is bound to precess just as our bicycle wheel did and will slowly swing around until it has placed its axis in line with the meridian, or in other words pointing true north and south. It has done as far as possible what the gyroscope is perpetually trying to do—place its axis parallel with that of the larger curve in which it is moving. Now let us unclamp the horizontal ring giving the gyroscope freedom to move in a vertical plane and slowly its axis will rise until it is parallel with the axis of the earth and points to the pole star. And there it will remain pointing, not to the magnetic north but to the true north, with an accuracy that knows no "variableness nor shadow of turning."

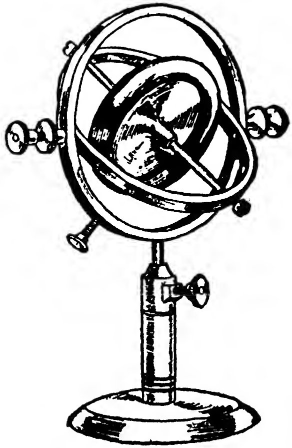


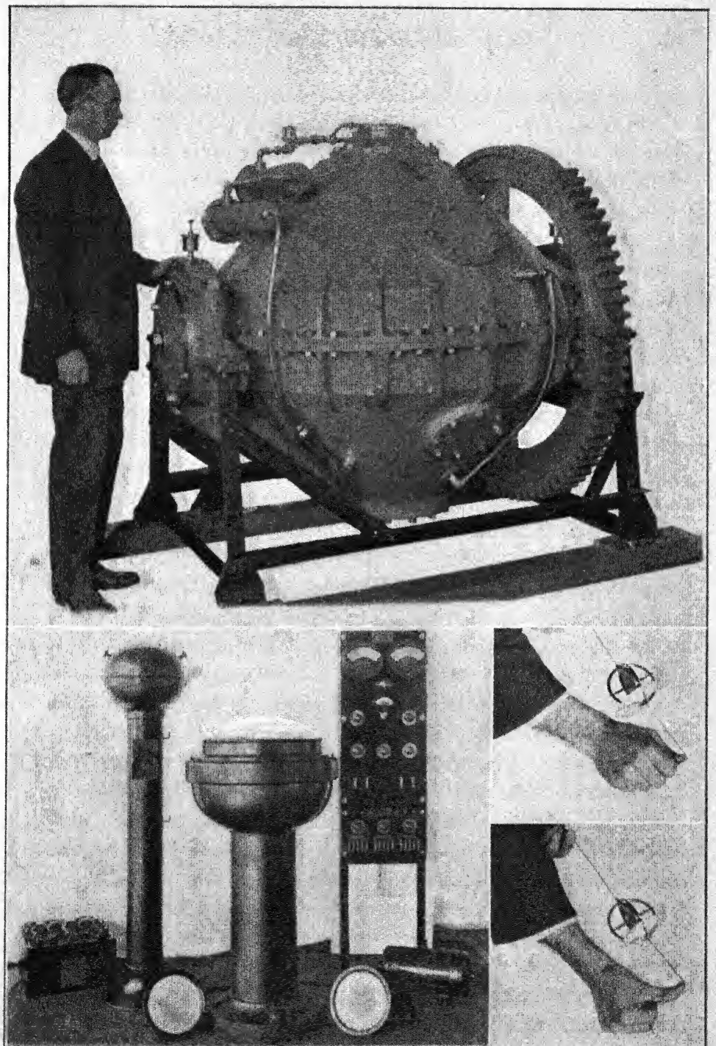
Fig. 2.—A gyroscope mounted with three degrees of freedom.

In a fixed position on land the operation of such a compass presents no difficulties, but when it comes to mounting one on a ship which may move in any direction and at the

same time be tossed by the waves, the gyroscope receives a "mixed" motion which deflects it from the meridian. But Mr. Sperry has overcome these seemingly insuperable difficulties and with the insight of true genius has perfected automatic correcting apparatus which neutralizes the effect of every variable influence. Like a creature of life this gyro-compass seems instinct with initiative and self control. Quicker than human thought it adapts itself to every change of motion and with unerring accuracy guides the mariner both on the surface of the sea and through its depths.

What the magnetic compass has meant to navigation cannot well be overestimated. With the advent of the steel ship, however, its use has become constantly more difficult. In the days of wooden ships practically the only influence that reached the delicately balanced compass needle was that of the earth's magnetic field. But the large masses of iron in a modern ship with their attractions for a suspended magnet have introduced disturbing factors which cannot easily be neutralized and which have destroyed much of the former usefulness of this instrument. The magnetic field of the earth is at best exceedingly weak and the directive force which it exerts is not sufficient to hold the needle steadily on the meridian. Then, too, the compass needle, except for a few places on the earth's surface, does not point to the true north but to the magnetic north and tables of declination giving the amount of this variation must always be consulted by the mariner in determining the real course of his ship.

Therefore, the invention of the gyro-compass which is entirely independent of all magnetic influences marks the greatest advance in practical navigation in recent years. Utilizing the immense directive force of the earth's rotation, an instrument of the highest precision has been produced



The ship stabilizer, the gyro-compass and a simple demonstration of gyroscopic action.

and one which points to the true north whatever may be the ship's position and course or however violently it may be tossed by the waves.

The first experimenter to utilize the principle of the gyroscope in a practical instrument was the great French physicist, Leon Foucault, about the middle of the last century. He mounted a gyroscope with three degrees of freedom and, as already described, was able to give visible proof of the earth's rotation. He carried his apparatus to England and exhibited it before the Royal Academy where he aroused the greatest enthusiasm. In 1878 the well-known American author and physical demonstrator, Hopkins, applied an electric motor to Foucault's gyroscope and was able to obtain much more certain results. The gyro-compass which he set up operated very well in a stationary position but when subjected to the varying motions of a wave-tossed ship it became practically useless.

As previously stated the man who has contributed most to the perfection of a gyro-compass of absolute reliability, one which automatically adjusts itself to every movement of the ship and points with unvarying accuracy to the true north is the American inventor, Mr. Elmer A. Sperry. A marvelous instrument is this eye of the ship. As one observes it in operation in Mr. Sperry's factory, subjected to artificial motions, more severe than any encountered in actual service, the unchangeableness with which it holds to the meridian gives the appearance of a living, throbbing organism endowed with intelligence and self control. But here again, just as in every other useful device, this mechanism is the product of human thought. Back of it stands the idea of the inventor translated into material expression. It is additional proof of the psychological truth that personality is the keynote of the universe.

Without the gyro-compass the navigation of the submarine would have been exceedingly difficult and its sphere of action greatly restricted. A magnetic compass is of little use on underseas craft owing to their steel structure and the weak magnetic field of the earth. The equipment for a battleship or submarine consists of a master compass and a number of repeaters conveniently placed about the ship and all under electrical operation and control. The heavy wheel of the master compass revolves in a vacuum case with a speed of approximately 8600 revolutions per minute. Its construction including the automatic correcting devices for changing motions is somewhat intricate but its operation is strictly in accord with the gyroscopic action already explained.

The Monorail Car.—To the imagination and genius of Mr. Louis Brennan, a young man of Irish birth, whose youth was passed in Australia, a country of great distances and at that time inadequate railway facilities, we owe the spectacle of a car that travels on a single rail, unsupported on either side yet balancing itself perfectly, sensitive to the slightest strain but secure and stable as a mountain side. A paradox it, indeed, seems to be, yet, as we shall see, strictly in accord with the laws of gyroscopic action. The same force that holds the earth's axis pointing invariably to the pole star or balances a swiftly rolling hoop operates here to give a wonderful exhibition of inherent strength and stability. To conceive of such a project, so revolutionary to all current ideas of locomotion and apparently in direct opposition to natural laws, and then to work it out to ultimate success is the mark of true genius.

As Mr. Brennan grew to young manhood surrounded by the vast spaces of Australia, he pictured in imagination the future of this great continent thickly peopled, dotted

with large cities and highly organized industrially and agriculturally. But there seemed to be one insuperable obstacle to this rapid development, namely, the great cost of railroad construction and certain very serious defects in the two-rail system. It is a very difficult matter to lay two rails exactly parallel and keep them so or to build a road bed so solid and secure that the rails will at all points be at the proper height. Any considerable deviation from the parallel condition results in severe side thrusts or even derailment and the depressions in the rails cause jolts and rocking, so violent as to make very high speeds dangerous and impossible. These defects were more common to the railways of Australia, undoubtedly, than they are to those of this country. As Brennan suffered the discomforts incident to travel there, he became convinced that the future of that vast area depended upon improved transportation facilities and he determined to solve this problem. Thus does the vision of the seer blaze the way of progress.

To overcome these defects there seemed but one way and that by means of a one rail system. Therefore, Brennan without any hesitation set himself to invent such a system. But how to make a car balance itself on a single rail was a baffling problem. Brennan had the idea. The means for its material creation were yet to be discovered and perfected. For years the problem was constantly with him. He could not get away from it. Having become familiar with the action of the gyroscope and its wonderful stabilizing power, he bought several models and began to experiment. At last he was on the right track. And then came a long period of experimentation in the laboratory, the workshop in which man hammers into material expression the ideas which his genius creates. He made tops and mounted

gyroscopes in a great variety of ways. He found that a picture frame mounted on two sharp pins could be balanced perfectly by placing within the frame a spinning gyroscope. When he replaced the pins with wheels, tandem fashion, not only would the frame balance itself but it would run on a stretched wire. So long as the spin was kept up the mechanism exhibited great stability. If one pushed against it the frame pushed back with an equal and opposite thrust. The problem seemed nearing solution, but Brennan soon found that his car would turn over on its side and leave the track at the first curve. Obviously it is impossible to build railroads without curves and therefore a new and very difficult problem had presented itself. As will be seen a little later, the cause of this mishap is a direct result of the laws of motion governing the gyroscope and its remedy seems very simple now. To Brennan it proved an obstacle which he was long in overcoming. The very law of motion which he was seeking to utilize as the stabilizing force of his car seemed likely to defeat his purpose and bring his years of thought and work to naught.. But perseverance knows no turning back and Brennan had no idea of abandoning his purpose. He went to southern France for a short rest but the problem of the curve perpetually haunted him. One morning he bought a toy gyroscope of a street vender, a very crude affair when compared with the elaborate ones in his own laboratory, but as he spun it and pondered its action in a flash there came to him the way out of his difficulty. He returned to England and very shortly perfected the first model of the Brennan car.

On May 8, 1907, Brennan exhibited his model before the Royal Society and later gave numerous public demonstrations at his country place. Here was a car that balanced itself automatically, pushed back with a very great force

against any thrust tending to drive it from the track, rounded sharp curves, climbed steep grades, followed the crookedest gas pipe with perfect ease and crossed deep ravines on a slender and swaying cable. If a heavy weight were placed on one side, the car did not fall but rose slightly to meet the load. If one thrust down on the edge of the car, it pushed back and rose. In rounding a curve the car leaned in slightly just as a bicycle rider does. Indeed, it seemed instinct with intelligence and life. And all on a single rail, as stable when at rest as when in motion.

A closer inspection revealed a two chambered compartment in the front of the car in which two small fly wheels rotated in vacuum cases at the rate of about 7000 revolutions per minute. These wheels, small but heavy, rotate in opposite directions and being mounted so as to permit of precessional movement constitute the balancing mechanism of the car.

Just how they operate will become clear from a consideration of the following figures and explanation. Brennan has simply utilized the very great inertia of a rotating body, which is free to precess, in balancing his car. But far from being in defiance of gravitation this balancing power is the direct result of well known laws of motion.

Figure 3 shows a gyroscope mounted with three degrees of freedom, that is, it may rotate about axis OA and at the same time turn on axis BC or DE. If the heavily rimmed wheel is set spinning, its inertia will keep its axis OA pointing in the same direction and will resist any effort to displace it. This resistance, however, will manifest itself by causing the gyroscope to turn or precess about one of the other axes. Suppose we attempt to force the axis of the spinning gyroscope down by applying pressure at A. The result is not a downward but a horizontal movement

of the whole mechanism to the left about axis DE. If now we apply a vertical upward pressure at A, the precession will take place in the opposite direction. Should we endeavor to hasten the precessional movement by exerting

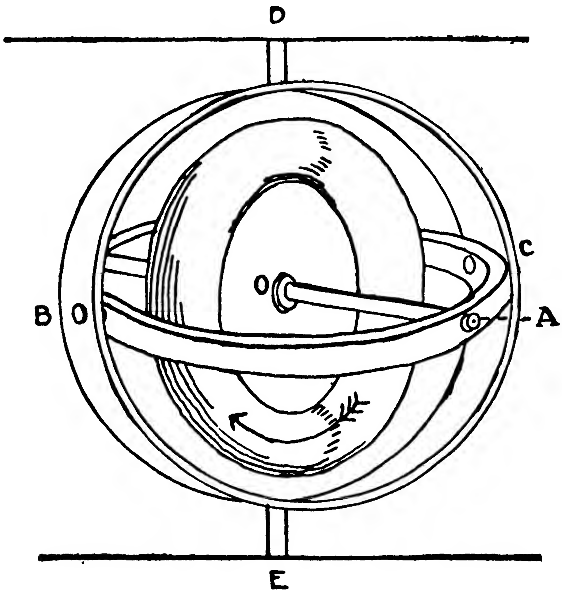


FIG. 3.

a sidewise thrust at A, the axis of the spinning wheel will either rise or fall. It will rise if we push to the left and fall if we push to the right. In any of these cases we are subjecting the gyroscope to two rotations at the same time and, just as in the case of the bicycle wheel, it attempts to rotate on the resultant axis lying between the two. And it makes no difference whether the gyroscope be subjected to one or several disturbing influences, each will have its

own effect. So long as the spin keeps up the action is automatic and instantaneous, the mechanism responding immediately to every influence, however slight. Its action is literally quicker than human thought. The amount of its inertia and therefore its stabilizing influence depends simply

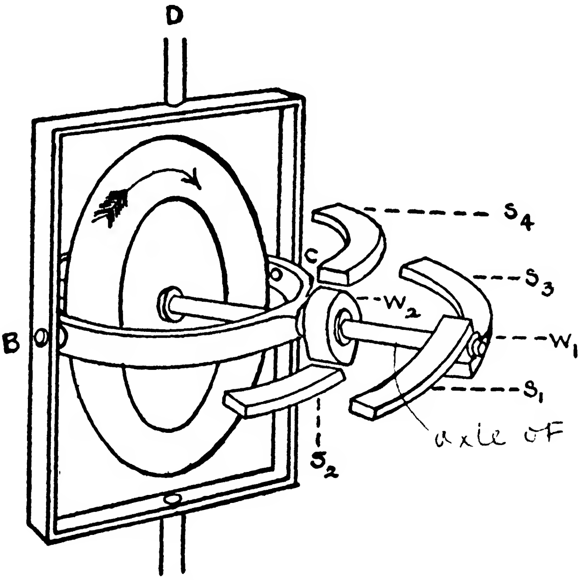


FIG. 4.—Gyroscope to illustrate the balancing action in the mono-rail car.

upon the mass of the gyroscope and the speed with which it rotates.

Now let us consider Fig. 4. This will explain the action of the gyroscope in balancing the mono-rail car. By means of the vertical axis DE the gyroscope is attached to the frame work of the car. The axle OF carries two friction

wheels, or rollers W_1 and W_2 which during the operation of the gyroscope will according to various influences come in contact with segments S_1 S_2 S_3 S_4. These segments are a part of the framework of the car. The roller W_1 is loosely mounted on the axle OF so that it is free to turn whenever pressed against the adjacent segments of the car frame. On the contrary roller W_2 is not attached to the axle but to an extension of the horizontal portion of the gyroscope frame.

Now let us see what will happen when a car running on a single rail and supplied with such a gyroscope is subjected to any of the variable influences such as the centrifugal force from rounding a curve, wind pressure, or the sudden shifting of passengers and freight. Suppose the car suddenly tips to the right from the weight of fifty passengers who move to that side of the car. This will bring segment S_1 down against roller W_1 and because of the friction between them the roller will immediately begin to run along the segment just as a locomotive wheel runs along the rail. But it will be seen that this is the same as a side thrust on the axle OF, pushing it to the left and, just as explained in Fig. 3, the result will be an upward movement of the axle. In other words as the car tends to tip to the right the automatic action of the gyroscope gives an upward thrust in the opposite direction, which causes the car to tip back to the left. This action will bring segment S_2 in contact with roller W_2 giving an upward thrust to the axle OF, but an upward thrust, it will be remembered, causes the axle to move to the right, thus bringing roller W_1 in contact with S_3 along which it tends to roll. This will increase the movement to the right and therefore cause the axle to be depressed downward, for a sidewise thrust to the right brings a downward movement of the gyroscope axle. This

downward movement will bring segment S_4 in contact with roller W_2 which will arrest the downward tendency and move the axle back to the left and into its original position. All this happens instinctively, as it were, and with lightning rapidity. Whatever the disturbing influence may be, this series of oscillations is set up and continues until the whole car is again in perfect balance.

But how did Brennan solve the problem of the curve? A little consideration will show that when the car is rounding a curve the gyroscope is subjected to an additional influence, the result of which is to throw the car over upon its side. With the gyroscope wheel spinning as shown by the arrow, the direction of its axis of rotation will be to the left, i. e., the direction which a right handed screw will follow in being turned. The axis of the curve, however, will always be vertical and it does not matter whether its direction is up or down our gyroscope in attempting to place its own axis along a line lying between the two will derail the car and with an irresistible force hurl it over upon its side. It will always fall, too, toward the inner side of the curve.

To solve this problem Brennan mounted in his car two gyroscopes of equal masses and linked together so as to rotate with exactly the same speeds but, and here is the point, he made the wheels rotate in opposite directions. Then when the car rounds a curve, as one gyroscope tries to tip it off the track in one direction the other is exerting an exactly equal force in its effort to derail the car in the opposite direction. Therefore the two forces neutralize each other thus destroying the effect of the curve. In all other respects one gyroscope has the same effect as the other, for the two gyroscopes are mounted on either side of the center line of the car and are in perfect balance. Therefore, as the car tips to the right for example causing a downward

thrust on one axle, there is a corresponding upward thrust on the other axle and since the gyroscopes rotate in opposite directions the resulting precessional movements will always be in the same direction, or better they will always be working together.

Although this type of locomotion at the time of its invention seemed to possess very decided advantages over the two-rail system, the world has not hastened to adopt it. Brennan received a grant of $30,000 from the India Society with which he built a car one hundred and sixteen feet long and balanced by gyroscopes three and one-half feet in diameter. This car did all that Brennan had claimed. Its stabilizing power was perfect and speeds very much greater than any now attainable seemed possible. The inherent merits of the gyro-car are still as potent as ever and the post-war period may see its extensive introduction.

Other Gyroscopic Devices

The Aeroplane Stabilizer.—In the summer of 1914 just preceding the great war in an international aviation meet held in Paris, Lawrence Sperry, son of the inventor, won the first prize awarded for the best automatic aeroplane stabilizer. The Sperry Automatic Pilot as the device is called is another application of the gyroscope. There are two gyro units which upon the slightest tipping of the aeroplane close electric circuits, thereby starting motors which move the regular aeroplane control surfaces just the right amount and hold the machine in its proper position. These gyros are sensitive to a tip of less than a degree and being instantaneous and automatic in their action are immensely superior to human control. This control covers both lateral and longitudinal tipping and in addition by

means of another device called the azimuth-gyro the aeroplane can be held in any desired direction, whatever may be the direction of the wind. In numerous demonstrations made in France and in this country this gyroscopic stabilizer has shown how completely the uncertain human factor may be eliminated from the problem of aeroplane control. In the great post war period of aeroplane development this stabilizer will undoubtedly have a very important part and it is now in use on military aeroplanes of all the allied powers.

The Ship Stabilizer.—Another gyroscopic device of which the public is destined to hear and experience much in the future is the automatic ship stabilizer. The physical discomfort incident to ocean travel in rough seas is so great as completely to discourage very many people from venturing upon a very long sea voyage. The time is at hand, however, when every transatlantic liner of importance will be equipped with a gyroscopic stabilizer which will render her decks in the roughest sea as free from pitching and rolling as though she were "a painted ship upon a painted ocean."

This device consists of a heavy gyro-wheel mounted on a vertical shaft set within a casing placed on horizontal trunions. The gyro-wheel rotates on a vertical axis, the ship in attempting to roll will turn it about a horizontal axis lengthwise of the ship, while the casing and with it the gyro-wheel within are free to precess about a horizontal axis crosswise of the ship. Thus it will be seen that here again we have a gyroscope with three degrees of freedom and its action with the pitching of the ship is exactly like that of the gyros in the mono-rail car. It is the fact that the wheel is free to precess that gives it its wonderful stabilizing influence. Were the wheel held rigidly in posi-

tion, though it rotated ever so fast, there would be no opposition offered to the action of the waves. This is shown on ship board by clamping the gyro rigidly, when the fury of the sea again takes full effect.

The United States government has equipped many of its cruisers and battleships with these gyros and their ability entirely to prevent rolling and pitching in the stormiest weather has been fully demonstrated. A ship may be rolling through an angle of from 30 to 45 degrees on either side of the vertical and groaning and creaking in every timber when the gyros are turned on and immediately all becomes calm. The decks become level, the quivering ceases and were it not for the visible evidences of a turbulent sea we should never suspect its presence. The waves seem to lose their impact, no water washes the deck, not even spray comes aboard and there is only a gentle rising and falling as the major waves pass under the ship. The wear and tear to which a ship is usually subjected at such a time is all absent. It has been found, too, that the ship is propelled through the waves at practically the same speed as though she were in still water. And she holds her course with very little helm.

The immense significance of this to navigation and ocean travel is at once apparent. An invention so calculated to rob the sea of its terrors and add to the world's enjoyment of it is destined to become a commonplace of the future. Many American yachts are now equipped with these stabilizers. The very great advantage of having a level gun platform on battleships can now be realized and it ought to add much to naval efficiency.

The first successful demonstration of the gyro ship stabilizer was made in 1906 by Dr. Schlick in the North Sea. The man, however, who has brought this device to

its present high degree of perfection is Mr. Sperry who invented the gyro-compass and the aeroplane stabilizer and with whose work we are now familiar.

The Steerable Torpedo.—The deadly torpedo owes the wonderful accuracy with which it is carried to the mark to the action of the gyroscope. As the torpedo is discharged a trigger projecting from the side of the firing tube releases the spring which starts the gyroscope spinning. Any deviation of the torpedo from the path in which it has been aimed tends to change the axis of rotation of the gyroscope, and the resulting precessional movement acts upon one of two valves connected with the compressed air reservoir which drives the torpedo's screw propellers. This admits air into a cylinder which forces a piston to move a rudder so as to steer the torpedo back into its path. If the torpedo swerves in the opposite direction the other valve acts in a similar manner.

The possibilities of gyroscopic action have by no means been exhausted and the future will undoubtedly see many new and interesting applications. Never forget, though, that the gyroscope presents no mystery and that its behavior is strictly in accord with natural laws. Like every other mechanism it is simply a link between the human mind and the great thought world of the Creator with which we are enveloped.

Some Experiments with the Gyroscope

Buy an ordinary toy gyroscope and perform the experiments described in the folder that accompanies it. Several illustrations of what can be done with this toy are shown in Fig. 5. Even so simple a toy as this demonstrates the great inertia and balancing power of the gyro-top.

The Compound Gyroscope.—Buy if possible a compound gyroscope similar to that shown in Fig. 2. As already explained such a gyroscope has three degrees of freedom. The

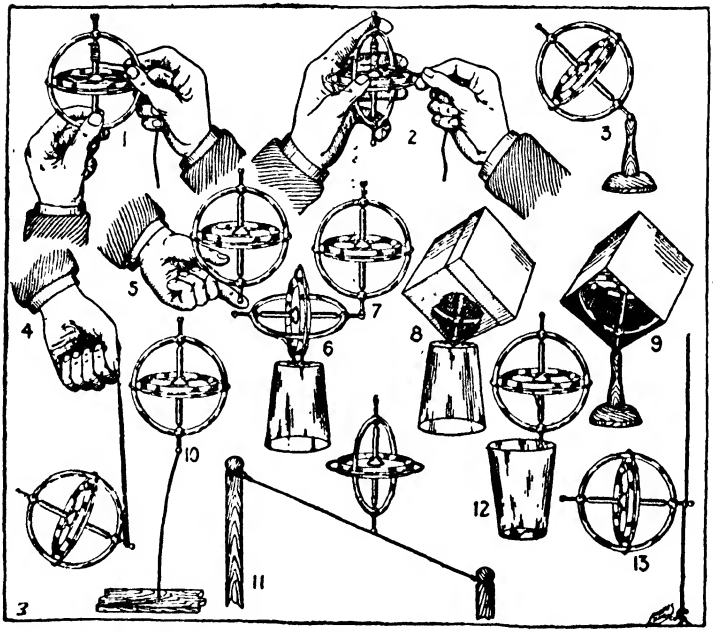


Fig. 5.

gyro-wheel rotates about one axis and is free to turn about two others, either one of which may be rigidly clamped if desired. A compound gyroscope may easily be made, too, from one of the toy gyroscopes. Mount such a simple gyroscope in a frame supported by a stand as shown in the figure and it will perform with perfect satisfaction all of the experiments to be described here.

Experiment 1.—Set the gyroscope to spinning with its

axis in a horizontal direction. The wheel will tend to remain in this position and will resist any attempt to displace it. Now apply a steady downward pressure to one end of the axle. The result is not a downward movement, as you might expect, but the whole frame moves in a horizontal plane about the vertical axis and at the same time tends to rise. The mechanism seems to be alive and to act in a manner contrary to the laws of material bodies.

Experiment 2.—Spin the gyroscope again with its axis in a horizontal direction and this time push steadily upward on one end of the axle. The result is a movement in a horizontal plane but in the opposite direction to the previous one and there is also a tendency to move downward.

Experiment 3.—Now spin the gyroscope and hang a weight on one end of the axle. Not only will the weight be supported but the whole frame will move slowly about the vertical axis. In other words the gyroscope precesses just as the bicycle wheel did. As the spin dies down the inner ring gradually drops from the horizontal and the precession stops.

Spin again with the weight on the opposite end of the axle and the precession will be in the opposite direction.

Experiment 4.—Spin the gyroscope with the axis horizontal and give one end of the axle a sharp sidewise thrust. The result will be either an upward or a downward movement about the horizontal axis depending upon the direction of the spin.

Push the axle in the opposite direction and the movement will also be in the opposite direction.

By performing these simple experiments you will verify for yourself the precessional movements of the gyroscope that are utilized in the balancing of the mono-rail car.

Experiment 5.—The effect of the earth's rotation upon

a spinning gyroscope may be beautifully shown with very little effort. Secure an ordinary toy gyroscope and attach strings to the frame as shown in the cut facing page 8. Also provide a small cardboard disc with the cardinal points of the compass marked as indicated. Now holding the string taut as shown but without the gyroscope spinning turn on the heel from left to right. Nothing happens and the axis of the gyroscope points indifferently in whatever direction it may happen to be.

Now set the gyroscope to spinning and holding it as before give a quick turn on the heel. Immediately one end of the axis of the rotating gyroscope comes uppermost and remains so. Turn on your heel in the opposite direction and with a quickness and energy that will surprise you, the uppermost pole will flop over and point downward toward your feet. As often as you reverse your direction of turning the gyroscope will reverse its axis of rotation and virtually rotate in the opposite direction.

Your turning corresponds to the rotation of the earth and has the same effect on the toy gyroscope that the actual rotation of the earth has on a gyro-compass.

To illustrate further, suppose an observer could be located out in space and looking directly toward the South Pole of the earth. Then if a number of gyro-compasses were set spinning any where on the earth's surface their axes would swing around until they were all parallel with the earth's axis and the compasses all rotating in the same direction as the earth's rotation.

CHAPTER II

THE TELEGRAPH

THE epoch-making inventions and discoveries are those which have contributed most toward the dissemination of ideas, the annihilation of time and space and the advancement of the economic welfare of the peoples of the earth. Judged by these standards no other invention of the last century, which might well be called the age of inventions, can claim higher rank than the telegraph. But like all great inventions it cannot be regarded as the work of a single inventor. From the earliest times men have felt the need of communicating with each other at a distance. The early Greeks, Romans and Aztecs devised means of signaling by means of beacon lights flashed from mountain top to mountain top and great monarchs sent messages to distant parts of their domains by establishing relays of courtiers to bear them. Many have been the signal systems which men have employed in their efforts to reduce the real and effective size of the planet upon which they live.

Not until current electricity and electromagnetism had been discovered, however, was any real progress made. One discovery or invention leads to another and on these as stepping stones the race moves forward. The works of Galvanni and Volta led scientists everywhere to experiment with the electric current and one of the earliest results was Oersted's discovery in 1819 that a current bearing conductor possesses a magnetic field and will deflect a compass needle. Thus it became possible to signal at a distance

by making and interrupting an electric circuit so arranged as to act upon a magnetic needle. This set men at work anew on systems of telegraphy. The most important telegraph of this type was the five-needle instrument of Sir Charles Wheatstone, which he patented in 1837.

In this telegraph a loop at the receiving end, which formed a part of the telegraph circuit, had suspended within it a magnetic needle. By closing the circuit the needle was deflected to one side or the other depending upon the direction of the current. Five separate circuits and needles with a sixth return wire were used in the first line. A code was devised and it became possible to send messages over considerable distances. Wheatstone continued to improve his instrument and by 1845 he had it reduced to a single wire system. The single needle by repeated deflections was made to point out any desired letters arranged on a dial. This system, although much inferior to the Morse telegraph invented and perfected at the same time, continued in use in England for many years.

Following Oersted's discovery of the magnetic properties of the electric current Arago, a French physicist, discovered that a piece of soft iron could be magnetized temporarily by passing about it a voltaic current. It was but another step for Sturgeon to invent the electromagnet without which so many modern electric devices would be impossible. As every school boy knows this consists of a soft iron core surrounded by a number of turns of insulated wire. The larger the number of turns of fine wire used, the more sensitive it becomes, a very weak current serving to actuate its armature. Then followed the perfection of the Daniell cell, a constant current cell which will maintain a steady current for long periods of time.

The ground work had now been done and the world was ready for the advent of the man of genius, the inventor who could take these newly discovered laws and first crude instruments and fashion them into the masterpiece which would "mark an era in human civilization and contribute to the comfort and happiness of millions."

The world did not have long to wait. Samuel F. B. Morse, born in 1791 at Charlestown, Mass., close to the birthplace of Benjamin Franklin, was destined to make "the first great commercial application of electricity." He was educated at Yale and there under the tutorship of Jeremiah Day, the professor of natural philosophy, received his first knowledge of the electric current. But his great interest was in art, and after graduation he devoted himself entirely to the study of painting, going to England in 1811 with the great American painter, Washington Allston, to continue his studies. Upon his return to America the following year he met with bitter experiences, finding the profession of painting unprofitable and the public indifferent to the products of his brush. In 1829 he again went to Europe for further study in the art galleries of Paris and Rome.

Three years later Morse found himself aboard the packet-ship *Sully* bound for America. One of his fellow passengers was Dr. Charles T. Jackson of Boston, who had witnessed Ampere perform experiments with electricity while in Paris. Dr. Jackson had secured for himself an electromagnet and one day in the cabin of the ship he exhibited it and described its action. And here we have one of the psychological moments in history, for Morse was immediately seized with the idea of transmitting messages over a wire by means of the electric current. Since every human achievement is the product of an idea, we may consider

the real invention of the telegraph as having been made at that moment. Its material creation was bound to follow. True, others had conceived of the same idea before but they did not carry it through to success. Before leaving the ship Morse had made drawings of a crude telegraph instrument and had plans for a recording as well as a signaling system.

Like most great inventors, Morse was afflicted with poverty and could devote but little time to experimentation. In 1835 he was appointed professor of the arts of design in the infant University of the City of New York. Here he set up his crude instruments and was able to send messages. The acquaintance which he made with Professor Gale, the instructor in chemistry, was a very great help. Morse's scientific training had been very meager and Gale brought him valuable assistance in this respect. Through Gale, Morse became acquainted with the work and discoveries in electricity of Prof. Joseph Henry, who had brought the electromagnet to great perfection, and had invented a system of signaling by means of it.

Morse had been working with an electromagnet which had but a few turns of coarse wire and was therefore very weak in its action. But several years before Professor Henry had demonstrated that a large number of turns of fine wire increased many times the sensitiveness of the instrument. Morse adopted this improvement and produced an electromagnet known as a relay which was sufficiently sensitive to respond to the weak line current. This line current when conducted over considerable distances was too feeble to operate the heavy sounder, but it would actuate the weak spring armature of the relay, and this armature was made to make and break a local circuit in which was placed a sounder and a strong battery. It was

this invention of the relay which made long distance telegraphy possible.

One day early in the autumn of 1837 there wandered into Morse's laboratory a young man by the name of Alfred Vail and as he observed a demonstration with the telegraph he became much interested in the new invention. He asked to be made a partner in the enterprise for he saw great commercial possibilities in it. Morse very readily assented to the proposal. Young Vail went to his father, an iron master of Morristown, N. J., for financial assistance and received it. Two thousand dollars were provided and Vail went to work in his father's foundry with all the enthusiasm of youth. He possessed considerable ability as a mechanic and made several improvements in Morse's crude model. The Morse code of dots and dashes as we have it today was worked out very largely by Vail. Assisted only by an apprentice boy, William Baxter, and an occasional visit from Morse, by January of 1838 Vail had a working telegraph. The two partners gave a demonstration that entirely satisfied the elder Vail and the telegraph was well on the way to success.

The essential for commercial success, however, was popular interest and to the development of this Morse next turned his attention. The public is always skeptical of new inventions and to overcome its apathy and indifference is a task as difficult frequently as the invention itself. New York and Philadelphia showed no interest in the "scientific toy." Morse then went to Washington with his telegraph and sought to enlist the support of the Committee on Commerce of the House of Representatives. He thought Congress should be willing to finance the building of an experimental line. At length Morse succeeded in securing the active interest of the chairman of the com-

mittee, Hon. Francis O. J. Smith. The rest of the committee was soon convinced of the utility of the new invention and a bill was introduced appropriating $30,000 for the construction of a line between Baltimore and Washington. Morse now seemed on the flood-tide of success and a company was formed for the promotion of the enterprise.

Stormy days, though, were ahead for Morse and his associates. Instead of remaining in America to drive his project through to an early and final success, Morse sailed for Europe to secure foreign patents and protect his rights abroad. In these efforts he was entirely unsuccessful and returned to America, only to find Dr. Jackson a claimant to a share in his invention and Congress indifferent to the appropriation for the experimental line. In the midst of poverty and disappointment, Morse was compelled t[illegible] art pupils as a sole means of averting starvation which he only narrowly succeeded in doing.

But Morse would not give up. He realized as no one else the tremendous possibilities of his invention. By means of letters and personal interviews with members of Congress he exerted every possible influence toward the passage of his bill. But many of the congressmen regarded the telegraph as the visionary project of a crank and were afraid to go on record as favoring it. At length in May of 1843, when Morse had been reduced to extreme poverty and had exhausted every resource of influence and persuasion, Congress passed his bill and the $30,000 for the first real telegraph line was appropriated.

Still disaster seemed likely to follow, for unexpected obstacles in the construction of the line presented themselves and much of the $30,000 was wasted without practical results. At length the promoters of whom Ezra Cornell, founder of Cornell University, was one, decided to string

Thomas A. Edison and Henry Ford examining a new telegraph device at the Panama Exposition, and Morse's original recording instrument.

the wires on poles instead of running them underground as originally planned. Finally on May 23, 1844, just one year lacking a day from the time Congress voted the appropriation, the first telegraph line in America was completed. On the following day, the anniversary of the appropriation, Morse sitting at the transmitter in the Supreme Court room in the Capitol telegraphed to Vail in Baltimore this immortal message, "What hath God wrought?" The telegraph was an accomplished fact and a new era in the affairs of men had been ushered in.

The operation of the telegraph is too well known to most boys to require much explanation here. And yet familiar as we are with it the telegraph always has a wonderful fascination. Even yet there is something awe-inspiring and mysterious about this sending of one's ideas over a wire. But since electricity travels with the velocity of light and can be made to flow or not at the will of an operator, signaling at a distance becomes just as feasible as sending the human voice through limited distances of space. One is really no more mysterious than the other. One is simply more common than the other. That is all.

In Fig. 6 are represented two stations which may be any distance apart. At each station there are key, relay and sounder. When there is no message being sent both switches are closed, and a continuous current flows in the line and also through the local circuits in which the sounders are placed. The negative side of the batteries at one station is grounded and the positive side at the other, the earth being used as a part of the circuit. If the operator at A wishes to send a message he opens his switch as shown in the diagram thus breaking the current at that point and demagnetizing every electromagnet on the line. Then as he presses his key current flows through the line and the

relays. This energizes the relays, drawing down their weak spring armatures and closing the strong local circuits which contain the heavy sounders. As the armature of the sounder is drawn down a sharp click results. By making

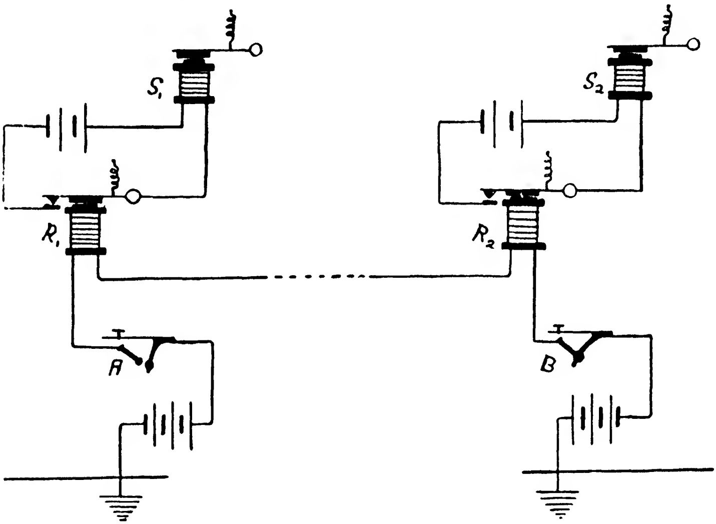


FIG. 6.—Diagram of telegraph line and stations.

these short or long the dots and dashes used in producing the signals of the code are made. Both relays and both armatures operate at the same time and if there are intermediate stations the instruments in those stations will also operate. Any operator on the line may read any message that is passing whether it is intended for him or not. But only one switch may be open at a time, for if the line were broken at more than one point it would be impossible to make and break the circuit. As already stated, the relay is an electromagnet wound with a large number of turns

of fine wire making it sensitive to the very weak line current. Then as shown in the diagram the armature of the relay makes and breaks the local circuit. This is a short circuit right within the station and the batteries for it are usually underneath the operator's desk. The line current is now-a-days supplied by a dynamo instead of by batteries. When an operator is through sending a message, he closes his switch so the line can be broken at some other point and another operator may use it.

In Morse's original instrument the armature of the sounder carried a pen which made marks on a moving strip of paper, a short one for a dot and a long one for a dash. Morse regarded this as one of the excellent features of his system but operators very soon found that they could take messages by ear with great facility and the recording attachment was abandoned.

Duplex Telegraphy.—As invented by Morse it was impossible to send more than a single message over a line at one time, but in 1855 J. B. Stearns of Massachusetts perfected a system by which two messages could be sent at the same time.

A consideration of Fig. 7 will make clear the theory of duplex telegraphy. The current from the battery at A divides and passes around the electromagnet in opposite directions, the two branches being balanced so that each receives the same quantity of current. The upper and lower halves of the magnet being wound in opposite directions tends to create a north pole and a south pole of equal and opposite strengths at each end and therefore the result is to keep the magnet in a neutral condition and to prevent its armature from being attracted. The conditions at the opposite station are exactly similar. It will be observed that when the key at station A is pressed there are two

paths for the current to follow. One is about the upper half of the magnet at A over the line about both branches of the magnet at B down to the earth and back to the negative side of the battery at A. The other is about the

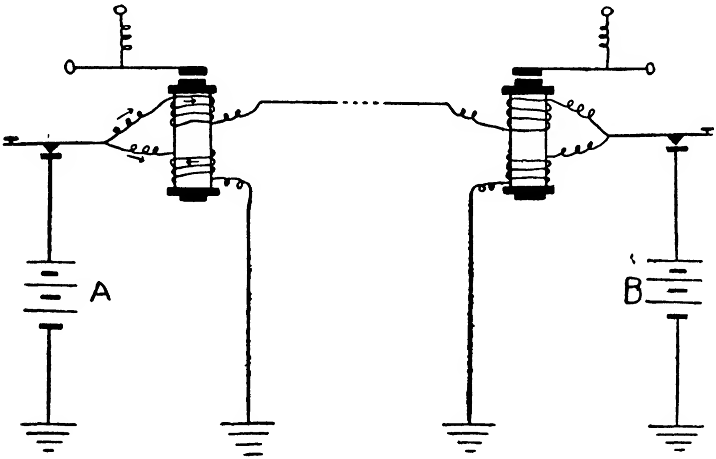


FIG. 7.—A duplex telegraph system.

lower half of the magnet at A down to the earth and back to the battery. Thus the fact that the operator's switch at station B is open does not interfere with the work of the operator at station A. Now suppose the operator at A is sending a message. His own electromagnet and armature remain inactive. But if at the same time the operator at B begins to send, the current from his battery passing about the upper half of his magnet over the line and about both branches of the magnet at A will actuate that magnet and put its armature in operation. The current from battery B is now flowing about the two branches of magnet A in the same direction and therefore magnetizes it.

There are other devices for accomplishing the same purpose and a little later Edison invented a quadruplex system by which four messages could be sent over the same wire at the same time. The saving in copper wire, cost of operation and rapidity of transmission resulting from these systems was very great and they were quickly adopted both at home and abroad. Had Edison done nothing else he would be entitled to lasting fame.

The Atlantic Cable.—No account of the telegraph would be complete which did not tell something of the clearness of vision and indomitable perseverance of that little group of men, who, against every obstacle of fate and man, accomplished the Herculean task of laying the first Atlantic Cable.

The first submarine cable was laid by Morse in New York Harbor in 1842 during those dark days of Congressional indifference to his great invention. In 1850 a successful cable was laid across the English Channel and two years later England and Ireland were connected by cable. In this same year a project was started to establish telegraphic communication between St. John's, Newfoundland, and New York, a part of the line to consist of a submarine cable across the Gulf of St. Lawrence. Running out of funds, F. N. Gisborne, the promoter, applied to Cyrus W. Field, a retired merchant of New York, for financial aid. The idea at once seized Field that an Atlantic Cable binding together the two continents was feasible and practicable. Both the British and American governments responded to his appeal for assistance and vessels from each navy were detailed to make soundings of the ocean bottom between Newfoundland and Ireland. The report was exceedingly favorable and Field with Morse as electrician formed a company for the prosecution of the enterprise.

Field went to England to secure capital and there organized the Atlantic Telegraph Cable Company which took the place of the American Company. He also enlisted the support of Charles T. Bright, a young Englishman as engineer for the company. But more important than the services of Bright was the association of Professor William Thomson, later Lord Kelvin, as an enthusiastic member of the enterprise. Professor Thomson was one of the foremost scientists of the time and without his able assistance the work could not have been carried to completion.

In August of 1857 the first attempt at laying the cable was made. For the gigantic task England loaned the *Agamemnon*, one of her largest warships, and the United States the *Niagara*. The *Niagara* did the actual work of cable-laying and stowed away in her hold were 2500 miles of cable consisting of seven copper wires insulated with the newly discovered gutta-percha and covered with tarred hemp. The little fleet steamed away from the Irish coast amid much ceremony and all went well until nearly four hundred miles of cable had been paid out. Then as the stern of the *Niagara* was lifted on a high wave the cable parted and could not be recovered. There was nothing to do but to return to port and abandon the enterprise for that year.

A second attempt was made in June of the next year and this time the two ships met in mid ocean, spliced the cable and proceeded in opposite directions. A terrific gale nearly wrecked the *Agamemnon* before reaching the meeting place, but on June 26th the splice was made and the ships started. Twice at distances of three and fifty miles respectively the cable parted and the ships steaming back to the meeting place respliced the cable and started anew. But when at a distance of four hundred miles the cable again parted,

Field and his associates were compelled to abandon the enterprise and return to England.

Several million dollars had been lost and much valuable time. It was by no means easy to raise funds for a new start, but Field and Thomson undismayed once more kindled faith in the members of the company and in July of the same year the *Agamemnon* and *Niagara* met in mid ocean for a third start. Although much anxiety prevailed on ship board no mishap attended either ship and on August 6th the *Agamemnon* reached the Irish coast and the *Niagara* the Newfoundland coast in safety.

Telegraphic communication was at once set up and an interchange of greetings passed between Queen Victoria and President Buchanan. Every honor both at home and abroad was accorded the promoters of the enterprise. But in the midst of these celebrations when the cable was scarcely a month old the last message passed over it. Ignorance of the electrical requirements for cable transmission had resulted in the use of too high voltages and the insulation of the cable had been ruined. The keenest disappointment prevailed everywhere and all but Field and his companions despaired of ultimate success.

With the Civil War on and previous disasters fresh in the public mind it was not easy for Field to enlist interest in a fourth attempt. This he did, however, and in July of 1865 the *Great Eastern*, a mammoth ship too large for existing piers and harbors, was commissioned for the undertaking and the expedition once more proceeded from the Irish coast. After nearly two-thirds of the cable had been laid the *Great Eastern's* machinery broke down and as she was tossed by the waves the cable parted and was lost.

A man of less indomitable faith and courage than Field would have given up, but he began all over. A year later

on July 13, 1866, the *Great Eastern* started on her second venture and this time it was crowned with success. In just two weeks the cable was landed in Newfoundland and from that day to this the world has never been without

FIG. 8.—Western Union Telegraph Office at 195 Broadway as it appeared in 1880.

transatlantic cable service. The lost cable of the previous year was recovered and since many more have been laid.

What the world owes to these pioneers of science and invention it will never know. It is difficult to estimate the tremendous influence of the telegraph in the development of the modern business world. The operation of the great

trans-continental railway systems would have been impossible without it. The opening of the vast areas of the West and their assimilation as an integral part of the nation would have remained dreams of the pioneer days. National unity as we understand it today would never have been realized. In a world without the telegraph the big city dailies, such powerful factors in the molding of public opinion, would have no existence. Commercial enterprise would have remained a dwarf. Provincialism and not internationalism would be the key-note of the future and that freest intercourse of nations which is to be the basis of ultimate world peace forever impossible. The world is prone to forget the debt it owes to the heroes of science who have made possible the great conquests of peace and war. What were but yesterday the marvels of inventive genius are become the commonplaces of today.

CHAPTER III

THE TELEPHONE ROMANCE

IF to flash one's ideas over a wire by means of dots and dashes produced through the operation of an electromagnet seems mysterious, then the transmission of the human voice along a similar wire by means of millions of tiny electric waves and its exact reproduction, hundreds and even thousands of miles away is little short of miraculous. To make an iron disc vibrate in response to the very slight energy of the human breath, three thousand miles distant, and actually to talk with the same tone and accent as though the speaker himself were present sounds like a tale from fairy land. But this is no longer a dream. It is rather a dream come true. We are living now and have been for nearly a century in a realm of scientific discovery and invention more wonderful than any fairy land constructed in the imagination of the most fanciful dreamer. And yet this is the age of dreamers, dreamers whose souls have caught the vision of mighty achievements and whose deeds are marshalling the great and unseen forces of the universe into the army of human service.

No seer of any age ever dared to dream of a project more fanciful or seemingly impossible than Alexander Graham Bell when he began to speculate on the possibilities of transmitting the human voice by means of electricity. And yet Bell was not an electrician. As he, himself, said, "Had I known more about electricity and less about sound, I never would have invented the telephone." Bell was a

master of acoustics, an elocutionist of some note and a teacher of deaf-mutes by a system of "Visible Speech" invented by his father. His whole family for several generations had been interested in human speech.

Bell was born in Edinburgh, Scotland, in 184[illegible]. After attending the public schools of his native city and subsequently studying on the continent, he went to London where he made the acquaintance of Sir Charles Wheatstone, the inventor of the English telegraph. Here he learned that Helmholtz had vibrated tuning forks by means of electromagnets and was thereby able to produce sound. Because of his very great interest in human speech and everything having to do with it, this production of sound by an electric current deeply impressed Bell and there was born in his imagination the idea of a musical telegraph. He thought it possible to devise a mechanism which would transmit several messages over a wire at the same time and by utilizing the phenomena of sympathetic vibrations enable each message to be received independently of the others. He knew that if he sang any particular note close to the strings of a piano, the corresponding string would answer him. Of little significance to anyone but a genius, this fact meant to Bell that there might be invented a musical telegraph which would carry simultaneously over one wire as many messages as there are notes on a piano. A wild dream no doubt and yet it was the nucleus about which the development of the telephone grew.

At the age of twenty-two Bell lost two brothers from tuberculosis and was threatened himself with the dread plague. Leaving his native land he came to Canada with his father in the quest for health. In the little Canadian town of Brantford he lived for a year, fighting down his tendency to consumption and busying himself by teaching

his sign language to a tribe of Mohawk Indians. In 1871 through an acquaintance made by his father, while lecturing on "Visible Speech" in Boston, the Board of Education of that city offered Graham five hundred dollars to introduce his system of teaching deaf mutes in a school which had just been established there. Bell accepted and from that time on he has been a resident of the United States and a loyal American.

Bell's work met with the utmost success and very shortly he was appointed to a professorship in Boston University where he might train others to teach his system. A little later he established a school of his own. For two years he had little time to think of the invention of a musical telegraph and the great success which attended his professional work seemed likely to result in abandonment of the idea.

About this time, however, there came to Bell as a private pupil a little deaf-mute, Georgie Sanders, who lived with his grandmother in Salem. Bell was engaged to give him private lessons and as a part of his remuneration was to live in the Sanders home. Here Bell was allowed the basement as a workshop and he also made a fast friend of the boy's father, Thomas Sanders, without whose sympathy and financial aid the invention of the telephone would have been impossible. Another private pupil of this time was Mabel Hubbard, a girl of fifteen who had lost her hearing and speech in infancy. She showed the keenest interest in Bell and all his work and four years later became his wife. Her father, Gardiner G. Hubbard, was a prominent lawyer of Boston and with Sanders gave the heartiest encouragement to Bell in the prosecution of his work on the musical telegraph.

Very soon the Sanders' basement became the scene of

all Bell's spare time. Here he brought his electrical apparatus and devices for the transmission of sound. No one was admitted to this sanctum, save the members of the Sanders' family, and he guarded with the greatest caution his ideas and work. In his enthusiasm for the great idea that possessed him, he neglected his teaching until only his two private pupils remained. Sanders and Hubbard financed his work. Giving little time to sleep and forgetful of the other members of the household, Bell worked incessantly toward the perfection of his idea.

Both transmitter and receiver of Bell's musical telegraph consisted of an electromagnet, to one pole of which was fastened a piece of steel clock spring. One end of the spring extended over the opposite pole of the magnet and was free to vibrate. A make and break key was provided for the transmitter which when closed energized the magnet and caused the spring to vibrate after the fashion of a modern electric bell. This vibration produced a note, the pitch of which corresponded to the pitch of the spring. By varying the length of the spring an indefinite number of notes could be produced. This vibrating spring at the same time made and broke the main line circuit. It was Bell's theory that if one of these electromagnets, or "vibrating reeds," as he called them, were connected in series with one of exactly the same pitch used as receiver at some distant point on a telegraph line and the reed set to vibrating, then the receiving instrument would be set in to vibration and produce an audible note corresponding to that of the transmitter. And Bell reasoned further that if six or eight transmitters, each having a different pitch, were connected to a telegraph line and an equal number of receiving instruments tuned to correspond were placed at various points, each receiver would pick out from the medley

of passing vibrations its own particular note and be thrown into sympathetic vibration. A perfectly plausible idea. Duplex telegraphy would be entirely overshadowed and the successful inventor would at once rise to wealth and fame.

But the longer Bell worked at his musical telegraph the more he became convinced that he was on the wrong track. Gradually there came into his mind the idea of sending the spoken word itself over the electric wire and reproducing it at the opposite end. His interest in the musical telegraph vanished and he devoted himself with even greater eagerness to the perfection of an actual talking telegraph. Bell reasoned thus, "If I can make a deaf-mute talk, I can make iron talk." Sanders and Hubbard, however, had no faith in his new idea and refused their further support unless he should continue his work on the musical telegraph which seemed to promise great practical results and to possess tremendous commercial possibilities. Therefore Bell worked faithfully for a certain period each day on the original idea and then turned with intense eagerness to his experiments in the transmission of human speech.

During all this time, too, Bell had been trying to perfect better methods in his system of "Visible Speech." He had experimented with a speaking trumpet as transmitter and a harp as receiver. These experiments led him to the discovery that a membrane thrown into vibration by the voice would make the sound waves plainly visible. He thought the deaf might be taught an alphabet of visible vibration. Dr. Clarence J. Blake of Boston suggested the use of a real ear as vibrating membrane and provided one for Bell's use. With one end of a straw fastened to the ear drum and the other free to move over a smoked glass, Bell was able to produce markings on the glass when he

spoke into the ear. Nothing of importance resulted for visible speech but this idea of a vibrating membrane was like the inspiration of genius to Bell at this point in his invention of the telephone. If a delicate ear drum would set into vibration the heavy bones behind it, why would not a vibrating iron disc set an iron rod or electrified wire into vibration? Although the means were all yet to be devised he was at last moving in the right direction.

About this time while on a trip to Washington Bell met Prof. Joseph Henry, who for a generation had been America's leader in electrical research, and received from him the utmost encouragement. To Bell's statement that he did not possess the necessary electrical knowledge for the perfection of his invention Henry replied, "Get it." Nothing could have heartened Bell more and he returned to his laboratory with a renewed spirit of perseverance that never forsook him.

This was in 1874 and Bell had moved his laboratory to Boston where he rented a room in the attic of William's electrical shop and employed Thomas A. Watson, an apprentice of the establishment, as assistant. Sanders and Hubbard were still supplying funds and Bell continued his work on the musical telegraph.

One hot afternoon in June, 1875, June 2, to be more exact, Bell and Watson were at work as they had been for months in a vain effort to tune into sympathy with each other the vibrating clock springs on the receivers and transmitters of their telegraph system. Watson was sending and Bell receiving. As Watson pressed the sending key, the contact points fused together and when he released it the current continued to flow. Consequently the spring would not vibrate but was held down by the electromagnet. In his efforts to locate the trouble Watson plucked the

spring causing it to vibrate. Bell came rushing into the room. A faint sound had actually passed over the wire and his keen ear had caught it. "What did you do then?" he demanded of Watson. "Don't change anything. Let me see."

In that moment the telephone was born. The plucking of the iron spring had varied the intensity of the current, which by accident was passing continuously through the electromagnets and line, and this varying current had caused the spring of the receiving magnet to be attracted with a constantly changing force and therefore to be thrown into vibration in exact unison with the sending spring. Just as the air is made to vibrate by the human voice so this vibrating reed produced sound waves. The fundamental principle of the modern telephone was operating in that crude apparatus and the whole world may be grateful that the right man was listening to its first faint cry. All that remained was to perfect discs or springs sensitive enough to be vibrated by the human voice and articulate telephony would be an accomplished fact.

The rest seems easy now but for forty long weeks the inventors worked, experimenting with every variety of vibrating disc and still the mechanism would not talk. And then on March 10, 1876, Watson, located in the attic, heard distinctly through the telephone receiver this message from Bell who was in the basement, "Mr. Watson, come here, I want you." Watson dropped his receiver and rushed to the basement, three flights below, shouting, "I can hear you. I can hear the words."

In the work of bringing the invention to perfection which immediately followed, Watson says, "I made and tested telephones with all sizes of diaphragms made of all kinds of materials—diaphragms of boiler iron several feet in

Bell's liquid transmitter used March 10, 1876, his tuned reed receiver and the first hand telephone.

diameter, down to a minature affair made of the bones and drum of the human ear, and found that the best results came from an iron diaphragm of about the same size and thickness as is used today. We tested electromagnets and permanent magnets, of a multitude of sizes and shapes, with long cores and short cores, fat cores and thin cores, solid cores and cores of wires, with coils of many sizes, shapes and resistances and mouthpieces of an infinite variety. Out of the hundreds of experiments there emerged practically the same telephone you take off the hook and listen with today, although it was the transmitter as well as the receiver."

On March 7, 1876, Bell had received a patent on his invention which has been called "the most valuable single patent ever issued." Although totally unlike the telegraph, Bell described his invention as "an improvement upon the telegraph."

Just at this time the Centennial Exposition was opening in Philadelphia and this offered to Bell precisely the opportunity he needed to place his invention before the public. Hubbard, who was one of the commissioners of the exposition, was able to secure an out of the way corner in the Education Building for the exhibition of the telephone. Being without funds Bell had not planned to visit the exposition himself, but as the train bearing Miss Hubbard was leaving the Boston Station, overcome by her grief on learning that he was not to accompany her, in rather dramatic fashion he boarded the train.

Arrived in Philadelphia Bell set up his apparatus and awaited the judges' tour of inspection. The public, always indifferent to new inventions, took no more interest in Bell's telephone than they had done in Morse's telegraph a generation before. The judges, too, were skeptical and

regarded the apparatus as a toy of no particular significance. "What if speech could be sent over a wire?" "Of what value could that be?" But just as the judges were about to leave Bell's exhibit without examining it, one of those dramatic moments of history arrived. Dom Pedro, the young Emperor of Brazil, with a company of gaily attired attendants arrived on the scene and greeted Bell with great fervor. The Emperor had visited Bell's school for deaf-mutes in Boston years before and had been much interested in the system of "Visible Speech." Dom Pedro was willing to test the apparatus and placing the receiver to his ear listened as Bell spoke. He dropped the receiver and in complete amazement exclaimed, "My God, it talks."

The judges were now all interest. Skepticism vanished. Each in turn listened to the human voice as it came pulsating over the wire carried by a million electric waves. Among the judges were Joseph Henry and Sir William Thompson, the latter declaring the telephone to be "the most wonderful thing he had seen in America." The great invention then became the most talked of exhibit at the exposition and was given a prominence for the remaining time worthy of its merit. Scientists, statesmen, business men—everyone flocked to see and hear this latest wonder of modern invention. Bell's name was on every lip and over night he had risen to world fame.

Although Bell had created the sensation of the exposition, the public in general were still skeptical. No one could see any possible use for the invention anyway. Therefore if Bell's telephone were to make fortune as well as fame for its promoters something must be done to popularize it. Hubbard undertook a campaign of publicity which had for its object the annihilation of the skeptics and the winning of public favor. One move was to arrange a series

of ten lectures to be given by Bell and Watson. A body of scientists, the Essex Institute of Salem, gave the first invitation for a demonstration. Bell gave the lecture and Watson acted as the man behind the scenes, being located in the Boston laboratory. A telegraph line connecting the lecture hall and the laboratory had been borrowed for the occasion. Watson would listen at the telephone and at the request of Bell played various musical instruments and, although not a singer, was required to render such favorite songs as "Auld Lang Syne" and "Yankee Doodle." These were heard by the audience in Salem and at the close of the lecture the members were invited to test the telephone for themselves.

This lecture aroused the greatest interest and invitations to repeat it came like a flood. Editors of newspapers awoke and gave it publicity. Indifference ceased and Bell became the most popular lecturer of the season. And yet this interest had no other object than entertainment. People flocked to hear Bell as they would to a circus. No one could see that the telephone possessed any commercial possibilities. But these lectures did bring results. They brought publicity and with their financial returns Bell was able to marry and sail for Europe on a wedding trip.

The first real telephone line to be established was between the Williams electrical shop in Boston and Mr. Williams' home in Somerville. Then in the month of May, 1877, the publicity campaign began to bear fruit. A man named Emery from Charlestown came into Hubbard's office one afternoon and laid down twenty dollars for the lease of two telephones. This was the first money ever received for a commercial telephone and in the encouragement which it gave to the promoters its value was more than a million dollars would have been a dozen years later. In this same

month, too, six phones were loaned to the owner of a burglar alarm system operating between six Boston banks and a central station. Here the first crude exchange was established. In a short time exchanges were established in New York, New Haven, Bridgeport and Philadelphia. One man secured the telephone rights for the entire state of Michigan for the asking and sold them a few years later for a quarter of a million. By August of that year 778 telephones were in actual use and Hubbard organized the "Bell Telephone Association" with Bell, Hubbard, Sanders and Watson as partners. Sanders was the only member of the company who had money but their capital was not sufficient to develop the enterprise and no one would buy stock. They offered the patent to the powerful Western Union Telegraph Company for $100,000 but the "electrical toy" was rejected.

The Western Union enjoyed a monopoly of wire communication and supplied many business firms with printing and dial telegraphs of several forms. These were so "superior" to the telephone that it was thought they could never be displaced. Then the unexpected happened. Several patrons of the Western Union removed the telegraph machines and replaced them with telephones. At once the Western Union awoke. If a real competitor had entered the field they must control it. Immediately the "American Speaking-Telephone Company" was organized with $300,000 capital and with Edison, Gray and Dolbear as electrical advisers. Edison was just beginning his great career, Gray had invented a musical telegraph and Dolbear had done work on a telephone which did not prove successful.

The result was magical. When the Western Union entered the telephone field skepticism vanished. Men were

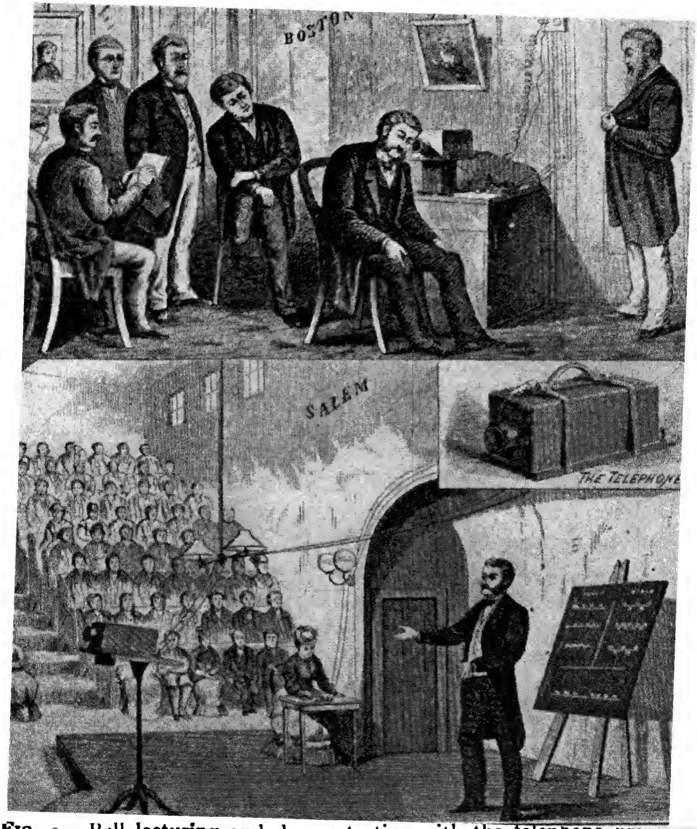


Fig. 9.—Bell lecturing and demonstrating with the telephone before the Essex Institute of Salem.

willing to see the commercial value of the new invention and orders for Bell phones began to pour in upon Hubbard by the thousand. Men stood in line to secure agencies. Organization and a business manager became essential. For this post Hubbard selected a young man named Theodore N. Vail, the head of the government mail service. He took up the work with an enthusiasm that has never failed and for nearly half a century has been one of the great captains of American industry.

Edison invented a new transmitter for the Western Union which was a vast improvement upon the Bell instrument. This gave the Bell competitors a strong advantage and enabled them to operate over much longer distances. Agents clamored for something equally as good and began to lose faith in the Bell Company. The Western Union, too, had a network of wires, a host of agents, forty millions of capital and great influence. Bell returned from Europe to find the affairs of his company in chaos and financial success apparently impossible.

But just at this critical moment there appeared on the firing line a young inventor, Clarence Blake, with a transmitter as good as Edison's. Furthermore he was willing to sell his invention to the Bell Company in exchange for stock. This placed the company on an equal footing with the Western Union as far as equipment was concerned but the warfare did not cease. Selecting Elisha Gray who had invented a musical telegraph and made application for a patent on a telephone which he never perfected, the Western Union began suit to establish the rights of Gray. The Bell Company fought the case with the ablest legal talent of Boston and the Western Union upon the advice of its own attorney that it could not prove its case dropped the suit and made peace. It was conceded that Bell was the original

inventor of the telephone and it was agreed that the companies should divide the business of wire communication between them, the Bell Company enjoying a monopoly in the telephone field and the Western Union having similar privileges in the domain of telegraphy.

The result of this controversy was to send the Bell stock up to $1,000 a share and the original promoters of the telephone, selling their interests, turned the development of the business over to other men. Each received a comfortable fortune and the reward which was his due.

The controversy as to who invented the telephone did not cease, however, and a bitter war of rival claimants followed. The most important of these contestants was Prof. Amos E. Dolbear of Tufts College. Professor Dolbear's interest was largely that of the scientific investigator and while he undoubtedly did pioneer work on telephone communication, he certainly did not perfect a practical instrument as was conclusively shown in the courts. In 1877, too, in a letter to Bell, Professor Dolbear accorded to him full credit for his great invention. No other patent has been so bitterly contested and no one's right to a great invention more clearly established than is Bell's to the telephone.

The period immediately following was one of organization and development. The first instruments were crude and clumsy. The same mechanism served for both receiver and transmitter. At telephone stations this important rule was usually posted, "Don't talk with your ear, nor listen with your mouth." Telephone switch boards were little more than a dream and of the simplest sort. Subscribers were listed by name and not by number and even when New York came to boast 1500 phones its directory contained no numbers. Calling a subscriber was accomplished

at first by tapping on the transmitter diaphragm with a pencil but this was very uncertain of results and injured the instrument. Therefore Watson devised a buzzer and finally the magneto call bell. The early exchanges were

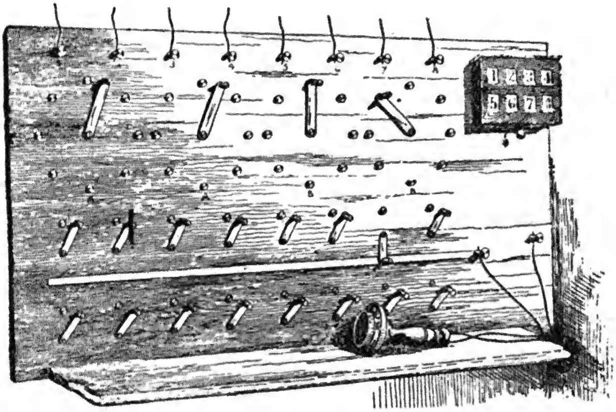


FIG. 10.—The first commercial switch board used in New Haven, Conn.

tended by boys and it required a half dozen boys and as many minutes on the average to answer a single call. Each boy talked at the top of his voice and ran about like mad. Pandemonium reigned and one of those early exchanges resembled a lunatic asylum let loose. To add to the utter distraction of all concerned a great medley of weird noises was always present in the telephone receivers at all times of day or night. What with tedious delays, impudent boys, feeble transmission and the never ceasing bable of noise, the telephone-using public did not suffer in those days it would be difficult to imagine.

But better times were to come. The Edison and Blake transmitters banished the single instrument for both sending

and receiving and also increased enormously the efficiency of transmission. Watson's magneto call bell and J. J. Carty's "bridging" bell by which several subscribers might be placed on the same line were immense improvements. The expulsion of the boys and the substitution of girls in the telephone exchanges was a heavenly innovation to a long suffering public. Then came Charles E. Scribner, the wizard of the multiple switchboard, which is one of the most complex mechanisms of modern invention. Without it telephone expansion would have been impossible. In the early days it required five minutes to answer a call and establish communication, but now, thanks to the magic switchboard, it is done in twenty-one seconds. The iron wire of high resistance and easily rusted away has been replaced with copper made capable of sustaining its own weight by a new process for making so-called "hard drawn wire." J. J. Carty the first and greatest of telephone engineers, who by the sheer weight of his own genius has developed a new profession, solved among many others the problem of underground noises and the maze of overhead wires. To eliminate the noises he substituted a return wire in place of the earth which had been used to complete the circuit in all of the early lines. The result was like magic. The unseemly noise disappeared and quiet has since reigned. The problem of overhead wires which obscured the sky, disfigured a city and broke with the sleet was solved by placing them in underground, moisture-proof cables, but without for a moment interrupting communication—a tremendous piece of engineering work. Then came the common battery, also the work of Carty, replacing the individual batteries along the line. The electric bell for signaling central was replaced with tiny electric lights and the device provided by which a subscriber

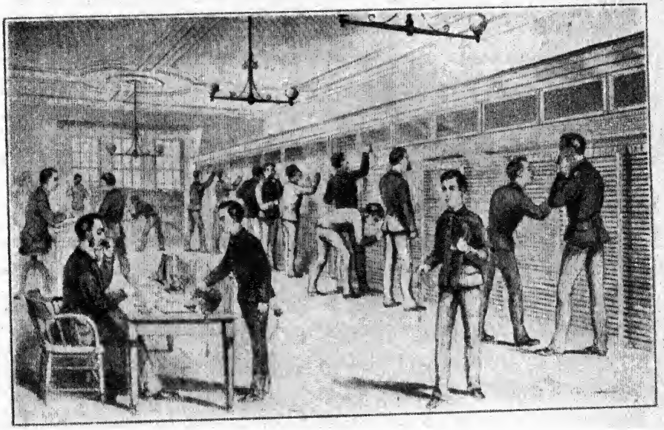


FIG. 11.—Cortland exchange in 1879.

may call central by simply removing the receiver from the hook.

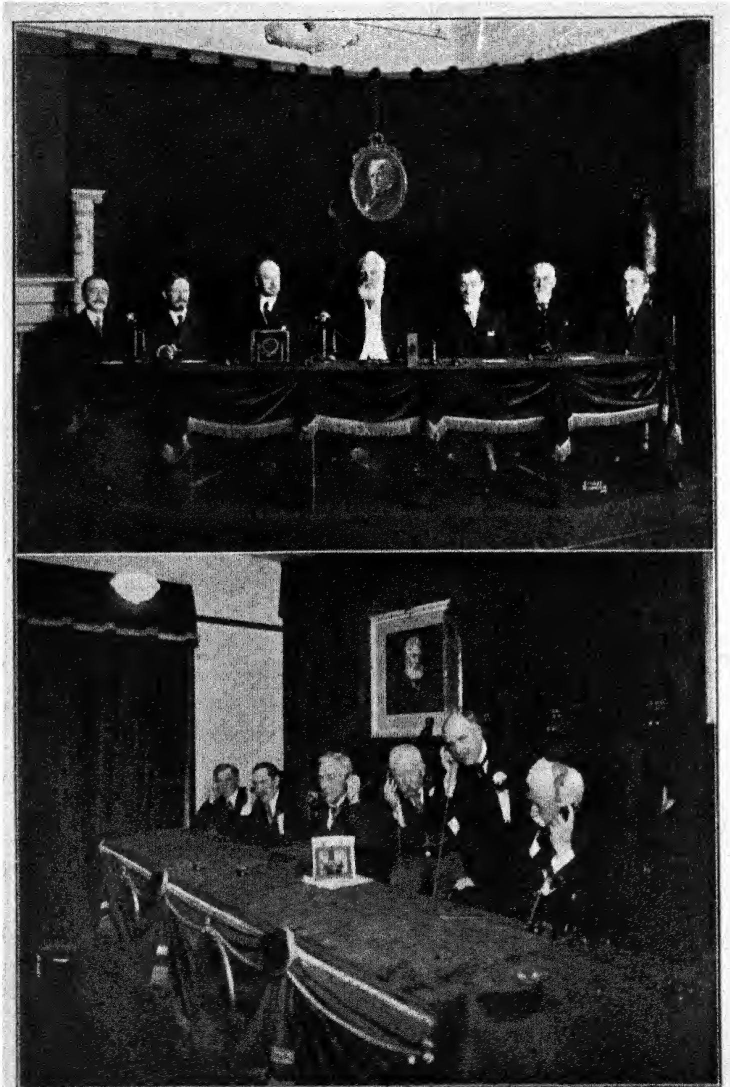
The Western Electric Company of Chicago and New York, founded in 1871 by an ex-telegraph operator, Enos M. Barton, became the pioneer manufacturer of telephone instruments and in 1880 began work for the Bell Company, a work that has grown to immense proportions. The making of telephone apparatus is very exacting and every instrument is subjected to the most rigid inspection. A single transmitter receives three hundred examinations and a coin box is made to count ten thousand nickles before it is put into service. The company now employs thousands of men and is the largest manufacturer of telephone apparatus in the world.

The marvelous expansion of the telephone system in less than forty years to embrace the whole world in a network of wires and cables and making it possible to throw the human voice from ocean to ocean is one of the mightiest achievements of American genius and enterprise. The man who in the early eighties had the vision, the faith and the courage to do the pioneer work and carry the development of the business forward to its present gigantic proportions is Theodore N. Vail who is still in active service. In 1879 he said, "I saw that if the telephone could talk one mile today, it would be talking a hundred miles tomorrow."

The Bell Company grew with a rapidity that was amazing. Earnings accumulated. The stock began to pay dividends that mounted into millions but represented only legitimate profits. By 1888 it was sending a million messages a day. Ten years later it had installed its first million telephones. By the close of the century it had strung a million miles of wire. Exchanges multiplied. In 1892 New York was talking with Chicago and very shortly

with Milwaukee, Omaha and other western cities. So was Boston. Today there are in the Bell system twenty-one million miles of wire connecting nine million telephone stations located everywhere throughout the United States and binding together in perfect communication one hundred million people.

Presently the genie of the telephone system began to dream of transcontinental service and then with characteristic American enterprise the dream became a fact. From New York to San Francisco by phone in less than one-tenth of a second is only a recent episode in the great telephone romance. With Theodore N. Vail and J. J. Carty, now General Carty, as leaders, the American Telephone and Telegraph Company carried its line across the plains, over the mountains, through the sage brush and down to the Golden Gate, opening transcontinental service on January 25, 1915. The line is 3,390 miles long. There are two circuits, each consisting of 6,780 miles of hard drawn copper wire. In each circuit mile 870 pounds of copper are used and 2,960 tons in the entire line. The loading coils for each circuit contain 13,600 miles of fine insulated wire 4/1000 of an inch in diameter. The line is strung on 130,000 poles and crosses thirteen states. The voice traveling by air at the slow rate of about 1160 feet per second travels across the continent by telephone in about one-fifteenth of a second or at the rate of 56,000 miles per second. Marvelous, you say, and so it is. When we consider that the very small energy contained in the sound waves of the human voice striking upon an iron disc is able to set up a train of electric vibrations which pulsating along a copper wire in perfect regularity break upon the Pacific Coast and reproduce more than three thousand miles away the very tone and accent of the speaker's



Opening transcontinental telephone service, January 25, 1915.

voice and all in the fraction of a second, well may we marvel.

But on that memorable afternoon of January 25, 1915, Dr. Bell speaking into an exact reproduction of his original instrument sent his voice, not a few feet, but 3400 miles from ocean to ocean and talked with Mr. Watson in San Francisco. Thus the two men who constructed the first telephone and sent and received the first message were the central figures in this latest achievement of wire communication. Imagination, sentiment, history, unrivalled progress, are all interwoven in the event. From the skepticism of 1876 to the crowning success of 1915, what a glorious chapter in the romance of American enterprise had been written. And yet, as we shall see, the vision of achievement did not pass. A still greater accomplishment was yet to come.

One great invention without which long distance telephone communication would have been impossible must be mentioned. It is the Pupin "loading" coil devised by Dr. Michael I. Pupin of Columbia University. What is called the electrical capacity of a long cable becomes so large that the alternate charging and discharging of this immense condenser, for such it is, so retards the transmission of a message, as to make long distance telephony impossible without some device to neutralize this capacity effect. To overcome this difficulty Professor Pupin used an inductance, or so-called loading coil, because he knew that inductance had the opposite effect to capacity and would neutralize it. These coils are placed every eight miles on the transcontinental line and on all other long distance lines. Thus it is seen how essential the work of the scientific investigator becomes to the commercial expansion of a great enterprise.

Another man who contributed very much toward the success of the transcontinental telephone is Dr. Lee De-

Forest, an American inventor and for two decades one of the world's leading investigators in the field of radio communication. He perfected and sold to the American Telephone and Telegraph Company the "Audion Amplifier" which, when connected in the line between a transmitter and distant receiver, amplifies to a marvelous degree "the voice currents, giving a reproduction of perfect fidelity without a trace of lag or distortion, yet with an increase of volume, or intensity." A description of this will be given under the wireless telephone.

What the telephone means to the world and has done for a quarter of a century and more no man can gauge. It spells communication and communication of ideas is the basis, of all material intellectual and social progress. The great network of wires and cables that tunnel beneath the rivers, cross the plains, climb the mountains and span the continent bind together in a great fraternity of business and social intercourse every part of the nation. Ocean sounds to ocean. Isolation has been banished. The farmer talks with the distant merchant and has literally brought the city markets to his very door. Mine and factory, though a thousand miles apart, are on speaking terms. Home and office are within sound of each other's voice. The great city dailies gather their news by telephone. The train dispatchers of the big trunk lines now shuttle to and fro the myriad carriers of life and commerce à la Bell instead of à la Morse. The Weather Bureau gathers its information and sends out its timely warnings for the protection of crops and shipping by telephone. The telephone is a slave to every director of our big corporations. Without it the wonderful organization and development of American industry would have been impossible. The foreman of a distant iron or coal mine sits in his underground

office and talks with the president of his company on the top floor of a New York sky scraper. The passenger in his stateroom on an ocean liner talks direct from pier to home or office. So does the occupant of a Pullman in our fast passenger service. In time of crisis—fire, flood or shipwreck, the telephone is the first to the rescue. Although the telephone has girdled the world, the United States is preeminently the telephone nation. In the Hudson Terminal Building of New York City alone there are more telephones than in the kingdoms of Bulgaria and Greece combined. The people of the United States talk with each other at the rate of more than seven billion conversations per year, a magnificent tribute to the pioneers and inventors who have made the telephone dream come true.

But it is in time of war that the telephone becomes indispensable. In the great battle of Mukden in the Russo-Japanese war General Oyama of the Japanese army sitting ten miles behind the line of attack directed every movement of his men by telephone as easily as though he were playing a game of chess. In the great World War one of the first acts of Great Britain was to establish telephone communication between London and the army field headquarters in France, then to connect the field headquarters with the divisions at the front and to provide temporary telephone lines in the combat zone. So well was this done that early in the war Sir John French from his home near Hyde Park, London, for three days directed the field operations in Flanders.

Close upon the heels of the army follow the telephone engineers and linemen. A cable drum mounted upon a limber unreels the wire which is hidden beside the road or strung on light poles. All wires from a given front lead to a central station behind the lines which consists of a switchboard carried on a wagon. Since the switchboard

can be operated without removal from the wagon the central office may be moved quickly to any point of the field.

Orders are given, cannon fired and army corps manipulated all by telephone. Scouts and spies move forward carrying portable telephones and quickly flash back to headquarters valuable information. Observation balloons carrying an officer with a telephone and paying out wire as they ascend give quick reports of enemy movements. Every part of the trenches is connected with every other part and with headquarters by telephone. The telephone outposts and the men who operate them figure in the most brilliant exploits of modern warfare and when the history of this great struggle comes to be written the heroism of the telephone branch of the signal corps will loom large in its pages.

Thus in peace and war the telephone has become a mighty servant of the race. What a tremendous echo now resounds from all the earth in response to the first feeble message from Bell to Watson in the Boston attic on that ever-to-be-remembered tenth of March, 1876.

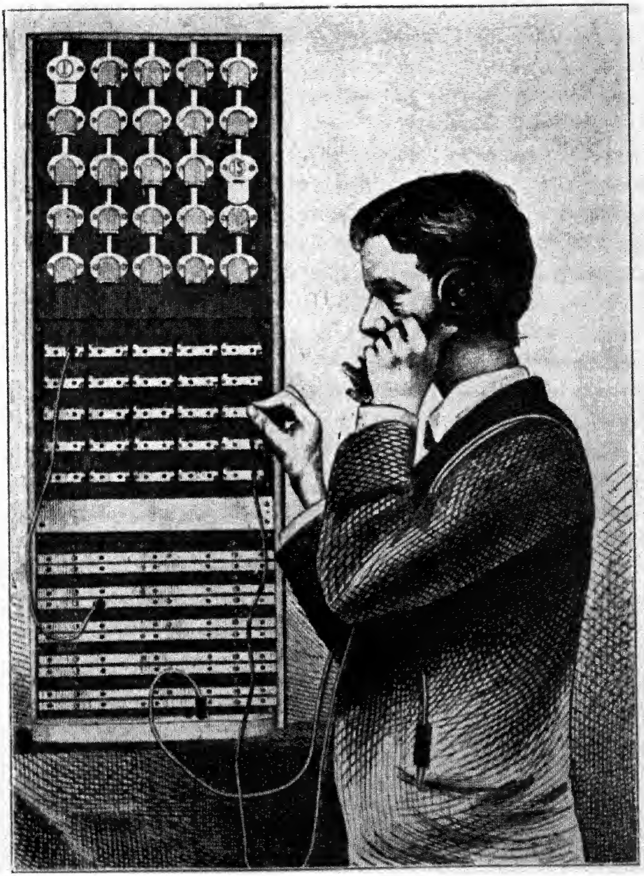


FIG. 12.—First universal switch board invented by Charles E. Scribner.

CHAPTER IV

PRINCIPLES OF THE TELEPHONE

The Theory.—The operation of the telephone in reproducing sound waves will become clear from a consideration of Fig. 13 which represents a very simple form. Two soft iron discs, E and E′, are mounted close to the ends of two

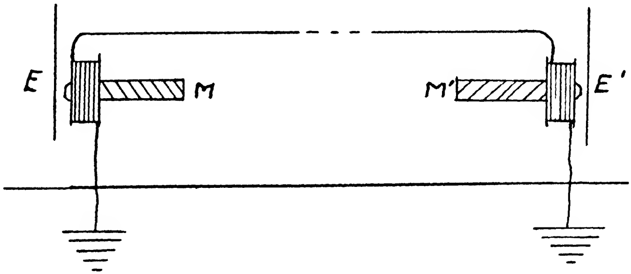


FIG. 13.

permanent bar magnets, M and M′, upon which are placed spools of fine wire. One end of each spool of wire is joined to a line wire and the other is attached to a copper plate buried in the ground. Now a bar magnet is surrounded at all times by a multitude of invisible lines of force passing from the north pole of the magnet through the air to the south pole and back to the north pole. These lines of force constitute the magnetic field and upon them depend all the properties of the magnet.

The fundamental principle of the telephone is that of induction, which may be stated as follows: Whenever mag-

netic lines of force are made to cut across a conductor an electric current is induced in that conductor. Soft iron has a great attraction for lines of force. Therefore in passing from one end of the magnet to the other these lines of force surge into and out of the soft iron disc. Now when one speaks against the soft iron disc, the condensations and rarefactions of the sound waves produced by the voice strike upon the disc and cause it to vibrate. A condensation is a compression in the air in which the pressure is slightly increased and this is immediately followed by a rarefaction in which the particles of air are less dense than usual and under diminished pressure. These condensations and rarefactions which correspond to the crests and troughs of water waves follow each other in regular order and beat upon the iron disc like the breakers upon the sea shore. As a condensation strikes the disc the soft iron is forced a little nearer to the end of the magnet and the lines of force surge into it still more and in doing so cut across the fine wire wound on the spool. According to the principle of induction this must induce a current in the wire which will travel over the line and about the other spool of wire down to the earth and back to the starting point. Then since a current bearing conductor always has a magnetic field of its own these lines of force from the induced current will strengthen the field of the opposite magnet and cause it to attract its soft iron disc at that end with an increased force thus drawing it in. As the rarefaction, consisting of air at diminished pressure strikes the disc, the pressure being removed, it moves away from the end of the magnet slightly and the lines of force surge out of the soft iron disc, thus cutting across the spool of wire in the opposite direction and inducing a current that will travel through the circuit in the opposite direction. The field of force of this

second induced current will of course have an effect opposite to that of the former and the pull on the disc at the other end of the line will be weakened causing it to spring outward. Thus it will be seen that these condensations and rarefactions striking upon one disc will, because of the currents which they induce in the line, make the opposite disc vibrate in perfect unison and therefore produce sound waves at that end of the line exactly similar to the original waves. Proof of this lies in the fact that we readily recognize a friend's voice over the phone. Now this was in principle the sort of a telephone with which Bell startled

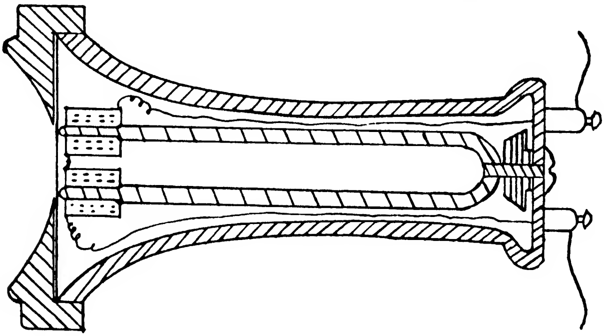


FIG. 14.

the world at the Centennial Exposition in 1876. We can understand now how Watson accidentally sent the first audible sound over the line on that hot afternoon of June 2, 1875. When the contact points of his transmitter fused together, thus closing the circuit, Watson by plucking the reed made it vibrate just as a telephone transmitter does and induced currents which caused the reed at the receiving end to vibrate in unison and produce a sound.

The Receiver.—A telephone receiver as shown in Fig. 14 consists of a permanent horseshoe magnet with a spool

of fine wire at each pole. The two spools are connected in series with each other and with the line. In front of the poles of the magnet is mounted a soft iron disc. Its action is exactly like that of the apparatus already described and in the original telephone lines this same form of instrument acted as both transmitter and receiver after the manner of a speaking tube.

An Experimental Line.—For short distances a very good telephone line may be made by connecting in series two

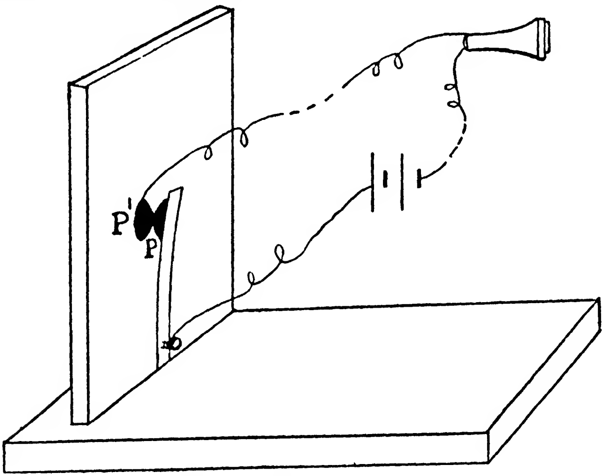


FIG. 15.—A microphone.

receivers. Use about number 14 copper wire for the line and ground one terminal at each end by connecting to a gas or water pipe. To insure good results it may sometimes be found necessary to use a second wire for the return instead of the ground. It was with such a line as this that Bell and Watson did their first real reciprocal telephoning from Cambridge to Boston Oct. 9, 1876.

The Transmitter.—It will be seen now that the problem

of inventing a separate transmitter consisted in devising a mechanism that would enable the sound waves to produce a variation of the magnetic lines of force, thus inducing the talking currents. The principle of the transmitter invented by Edison and in modified form by Blake is well illustrated in the simple microphone.

Points P and P^1 in Fig. 15 are carbon buttons, one being fastened to a strip of pine wood sounding board and the other to a brass spring which holds the two buttons in contact. The two buttons are connected in series with a dry cell and a telephone receiver as shown, the receiver being placed at a considerable distance away. Now if a watch be placed on the base or a faint sound be made by the scratching of a pin the sound waves produced will vary the resistance between the very sensitive contact points of the carbon buttons and therefore alternately increase and decrease the battery current which flows through the telephone receiver. As already explained this will cause the iron disc of the receiver to vibrate and repeat the sound with great distinctness. Any boy can readily make such a microphone and test this principle for himself.

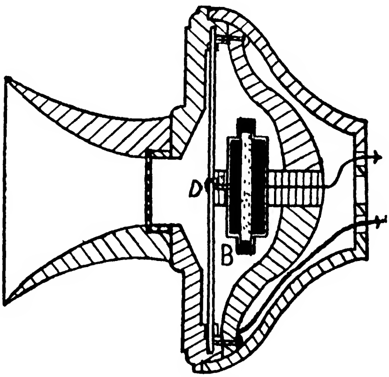


FIG. 16.

Blake's transmitter made use of two carbon pencils as in the microphone. One of these pencils is fastened to the vibrating iron disc and the two are placed in series with

the battery current. The modern transmitter as developed by the Western Electric Company is shown in Fig. 16 and as will be seen it contains a small box of granular carbon B through which the battery current must pass. The aluminimum diaphragm D connecting with one of the battery wires is in contact with one side of this box of granular carbon and as sound waves strike upon it is set into vibration alternately exerting pressure upon the carbon and then releasing the pressure. This action in turn decreases and increases the resistance of the battery circuit thus causing first more and then less current to flow.

The Line.—The arrangement of both transmitter and receiver for two stations is shown in Fig. 17. Here as will

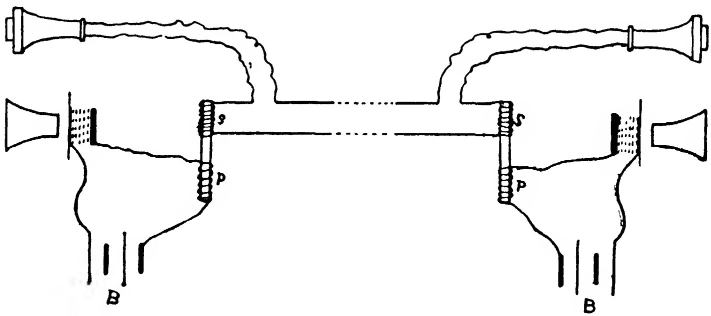


FIG. 17.

be seen there are two circuits, a primary and a secondary. In the primary circuit are placed the transmitter and batteries, in the secondary the receivers in series with the line. The coils of wire at P and S are wound upon a soft iron core and constitute a small induction coil. The primary P consists of comparatively few turns of coarse insulated wire and the secondary S of a large number of turns of fine wire. In practice the secondary is wound on a

spool surrounding the primary. Now as the condensation and rarefactions of the sound waves strike upon the aluminum disc of the transmitter the disc is set into vibration and as already explained alternately increases and decreases the primary current. This variation of current also produces a corresponding increase and decrease in the strength of the magnetic field in the primary of the induction coil, the lines of force surging outward and inward across the secondary and inducing talking currents in the line. These talking currents pass through the receivers increasing and decreasing the fields of the permanent magnets in them and causing their soft iron discs to vibrate in unison with the transmitter disc. The result is, as all the world knows, the production of sound waves which exactly duplicates the speaker's voice. Such a system as this with batteries at each subscriber's phone is the one in common use among the local lines of country districts.

The Central Station System.—In the modern central station system the individual batteries have been discontinued and the primary current is supplied by a battery of about 24 volts at the central station. The essential parts of such a system are shown in Fig. 18. As the subscriber removes the receiver from the hook the line circuit is closed at contact D and the current flows from battery B in the central station through the electro-magnet E. This electromagnet closes the small shunt circuit through the glow lamp L which is directly in front of the operator. Upon seeing this signal the operator immediately inserts the answering plug P into the subscriber's jack J, and presses the listening key K which connects her own receiver with the line. The subscriber gives the number which he wants and the operator inserts the calling plug into the jack of

the desired line at the same time pressing the ringing key K′ which throws an alternating current from the magneto M onto the line. When the subscriber being called answers, the operator throws out her own listening key and the

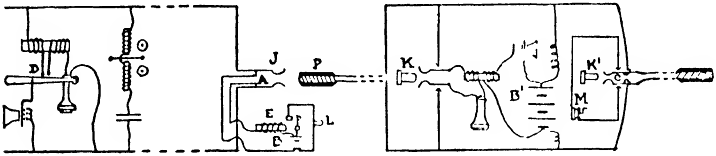


FIG. 18.

two parties are directly connected. As the subscribers hang up their phones a second lamp not shown in the diagram lights signifying that the conversation is ended. The operator then immediately removes the plugs and the lines are disconnected.

It will be observed that the first signal lamp to light goes out on the insertion of the operator's plug by opening the contact points at A. Also the first subscriber is momentarily cut off when the ringing key is pressed by opening the contact points at C. Otherwise the first subscriber's bell would ring too.

The call bells are polarized bells which respond to an alternating current but not to direct current. The condenser also breaks the circuit for a direct current but not for an alternating current.

A Simple Telephone.—A very simple but very sensitive telephone can be made by any boy as follows:

To a piece of board about five inches long, four inches wide and a quarter of an inch think mounted on a wooden base fasten two vertical carbons about three-sixteenths of an inch in diameter. Small claw tacks may be used for fastening the carbons. Place a hook at the middle and

top of the board and on this hang a piece of light soft wood carrying another carbon placed crosswise. This carbon should rest lightly against the two vertical carbons. This combination constitutes a very sensitive microphone transmitter. Now attach wires to the vertical carbons and carrying them through holes in the upright board connect the carbons in series with two dry cells and a

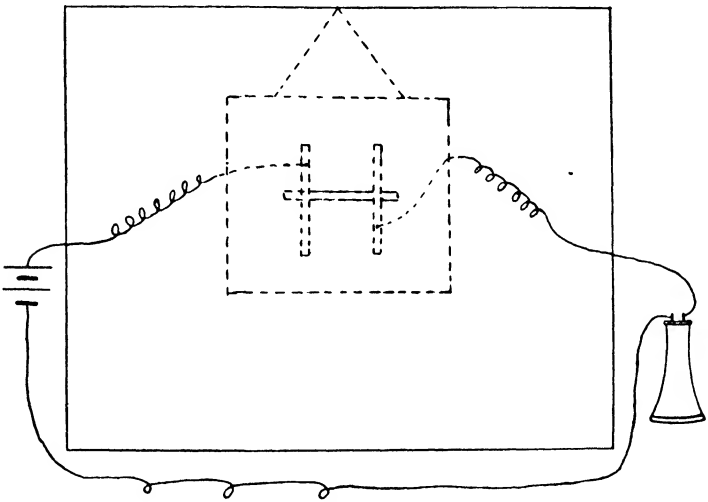


FIG. 19.—A simple telephone.

telephone receiver. The latter may be placed at distances of several hundred feet from the transmitter. The carbon placed crosswise and resting against the vertical carbons makes a poor contact in the circuit and as the sound vibrations strike upon the mouth piece the alternate increase and decrease in pressure which results varies the current flowing through tne receiver and causes its iron disc to vibrate, reproducing the sound.

A Home-make Telephone.—Any boy may have the pleasure of constructing a pair of simple telephone instruments and building an experimental line similar to Bell's first line with very little work and expense.

First secure an extra strong steel magnet about 5 inches long and preferably round. Over one end slip a piece of stock-fibre tubing and two tight fitting washers of the same material to serve as a spool. On this wind 200 turns of No. 26 double covered copper wire. Mount the magnet and spool on a base as shown in the diagram. The magnet should fit loosely enough in the upright to permit of moving it backward or forward in making adjustments. Now from any telephone manufacturing company or electrical store obtain two soft iron discs such as are used in telephone

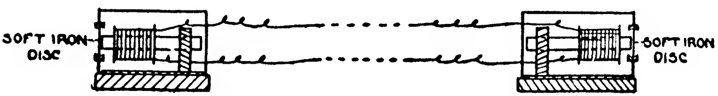


FIG. 20.—An experimental line.

receivers. Cut a circular hole in the end of a box about 4 inches high and 6 inches long and cover it with the soft iron disc. Mount the box over the magnet bringing the disc very close to the end of the magnet but not quite touching it. Using about No. 14 copper wire for the "line" connect this instrument with an exactly similar one some distance away. There should be a second return wire rather than using the ground for the return.

Making use of each instrument as both transmitter and receiver, just as Bell did, test the talking qualities of your line. You will be surprised at the results. In order to secure the best results, however, it will be necessary to adjust very carefully the distance between the iron disc and the magnet.

The operation of this line is exactly the same as that of any other telephone line. As sound waves strike upon the disc of one instrument causing it to vibrate a varying magnetic field of force is made to cut across the turns of wire on the spool. This cutting of the lines of force induces a current in the wire which traveling about the other magnet alternately increases and decreases the pull on the disc throwing it into vibration and reproducing sound waves identical with those spoken into the transmitter.

Such a line may be constructed from one house to another or from garret to basement and both pleasure and instruction derived from its use.

CHAPTER V

THE TRIUMPH OF WIRELESS

The world had scarcely mastered the awe with which it regarded the telephone when the wizardry of wireless fairly swept it off its feet. If sending the voice over an electrified wire is awe inspiring, and it surely is, what shall we say of this latest mastery of the realms of space without the aid of any material medium whatever? Truly, this signaling for vast distances with only the boundless ether to conduct our message seems little short of magic. The rapid progress made, too, by these genie of the radio art has appeared to the populace like the triumphant march of a group of giants moving forward in seven league boots. One success has quickly followed another until from signaling a few feet without wires we may now wireless a message a quarter of the distance about the globe. And what seems today the limit of possibility may be but a stepping stone to a greater success tomorrow.

Although Guglielmo Marconi is the master genius whose faith and vision have led to the triumph of wireless communication, it is equally true that many other pioneers of science have contributed to this great achievement. Probably one of the first to make use of the water as a conducting medium for the transmission of telegraphic messages was Morse during those dark days of patient waiting for the assembling of a Congress favorable to his great idea. As shown in the diagram, he submerged plates on one side of a river at a distance of about three miles

apart and connected them in series with batteries and a key. On the opposite shore he placed similar plates and in circuit with them a sensitive galvonometer. When the key was pressed a current flowed from the batteries to E_1 and here it divided, part going to E_2 and back to the

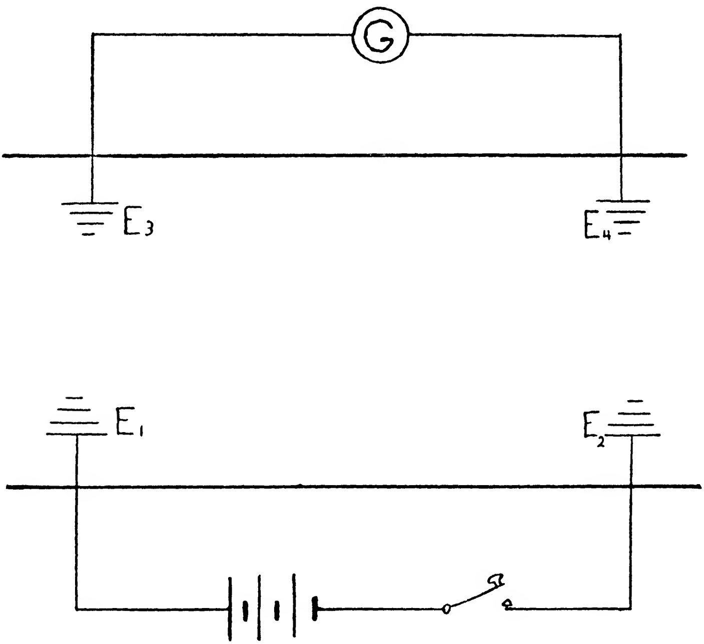


FIG. 21.—Morse's "wireless" system.

battery and the remainder passing over to E_3, through the galvonometer and back to the battery by E_4 and E_2. The galvonometer recorded the current and thus signaling by water connection became possible. Although not wireless as we understand it today, yet this was to some extent

sending messages without wires and as we shall see had several important applications a half century later.

Nothing further of importance occurred in the development of wireless telegraphy until after the invention of the telephone. The telephone receiver gave a wonderfully sensitive instrument for the detecting of very small electric currents. In 1880, Professor Trowbridge of Harvard University demonstrated that if the terminals of an alternating current dynamo were grounded electric vibrations would spread through the earth and might be detected by grounding the terminals of a telephone circuit. He varied the experiment by substituting an induction coil for the dynamo and grounding the secondary terminals. The currents thus transmitted were so feeble for anything but short distances, however, that no practical results came from these experiments. They were of immense scientific interest, though, and furnished material for those who were to follow.

Professor Trowbridge also worked out a plan for transatlantic communication using the water as a conductor as Morse had done a generation before. But the practical difficulties and the cost of operation seemed to prohibit this method and the idea was abandoned. Trowbridge suggested a similar plan for wireless communication between ships at sea and Dr. Bell a few years later succeeded in accomplishing this for ships half a mile apart. The indefatigable Trowbridge still persisting in his efforts discovered that if a coil of wire be raised in the air and a current sent through it, there would be induced in a similar coil facing it and at some distance away currents that might be detected with a telephone receiver. To transmit for even short distances, however, required enormous coils and large currents making this method impossible.

Trowbridge was approaching the real solution of the problem and will always receive large credit for the pioneer work which he did.

Professor Dolbear, who had previously done work on the telephone, was one of the early investigators of wireless communication. He used an induction coil and sent powerful currents into the earth being able to detect them at a distance by means of a telephone receiver as Trowbridge had done. He took out a patent on aerial antennae, and in 1879 invented a static telephone which in a very remarkable way anticipated wireless telegraphy. Professor Dolbear, however, did not develop a working system of wireless. He was rather the prophet who caught the vision of a great achievement and had supreme faith in its ultimate triumph but did not contribute the painstaking work and drudgery essential to practical success.

Another very interesting and it would seem practical application of wireless was made by Edison in 1885. He patented a system which enabled moving trains to send and receive messages at any part of the line. Small aerials eighteen inches high to which was connected sending apparatus were placed on the tops of the cars and grounded through the steel framework and rails. The ether waves sent out from these aerials induced currents in the telegraph wires running parallel with the track, which traveled to the stations along the line. The speed of the train did not interfere in the slightest with the transmission and the system was in every way a success. It failed though of any extensive commercial application and Edison turned to other lines of investigation.

Now the scene shifts to Europe and America was to be denied the honor of inventing and developing wireless as it had done the telegraph and the telephone. The next

man to figure prominently in wireless work was Sir William H. Preece, Engineer-in-Chief of the Postal Telegraphs of England. Adopting the methods of Morse and Trowbridge, Preece early in the 80's succeeded in establishing wireless communication between the Isle of Wight and the mainland of England when the cable between the two places had been put out of commission. Erecting parallel circuits on the opposite shores with their terminals submerged in water, he placed batteries and a telegraph key together with a telephone receiver in each circuit with perfectly satisfactory results. By 1892, Sir William Preece and A. W. Heaviside, were signaling across a space of ten miles by means of parallel telegraph lines. Mr. Heaviside, too, was able to communicate with mines nearly four hundred feet deep by laying wires on the ground above and arranging similar circuits in the mine. About this time communication was established with the light station on Fastnet Rock seven miles off the coast of Ireland. Owing to the exposed position of this station and the extreme violence of the waves cable communication was constantly interrupted. To remedy this the cable was cut not far from shore and anchored to the bottom. Telegraph wires were submerged at either end and service was maintained without difficulty.

But no one up to this time had really grasped the theory of wireless communication. Many experimentors had demonstrated its possibility and were groping in the dark, as it were, for better and more efficient means. It remained for Heinrich Hertz, a young German scientist, professor of physics at Carlsruhe and former pupil of Helmholtz, in that series of now classic experiments, to demonstrate the possibility of signalling through the all pervading ether of space. Clerk-Maxwell, the great Eng-

lish physicist, had in 1864 shown theoretically that light is due to electro-magnetic vibrations, but being a mathematician rather than a scientific experimenter, he was unable to prove his theory. In 1886, in his epoch making

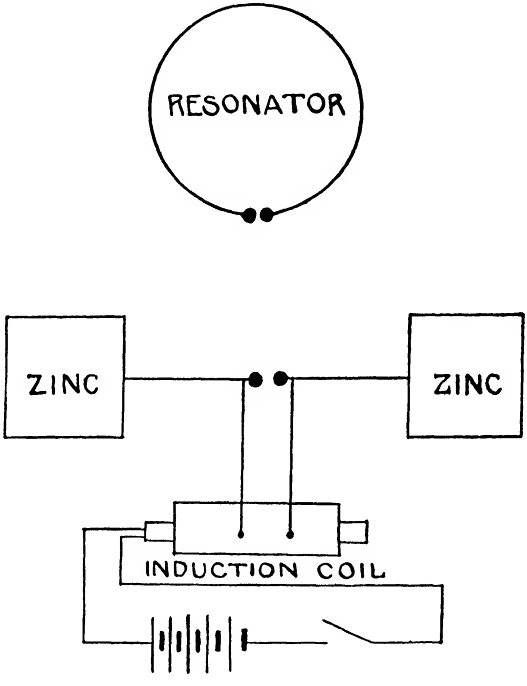


FIG. 22.—Apparatus for demonstrating the Hertzian waves.

discovery that there are ether waves possessing all the properties of light waves but of much greater length and lower pitch, Hertz confirmed the prophecy of Maxwell and set at work a host of experimenters in this new and delightful field of scientific research.

Hertz carried out his experiments with an induction

coil, what we should now call a crude aerial and a resonator. An induction coil, explained in another portion of this book, is a piece of apparatus for changing currents of low voltage and relatively large quantity into high voltage and small quantity. There are two circuits, a primary and a secondary, the latter containing a gap across which a powerful spark discharge occurs when the primary circuit is broken. Leaving a small gap between the terminals of the secondary, Hertz connected to each side of the gap copper rods about twelve inches long and terminating in plates of brass or sheet zinc fifteen inches square. As these plates become highly charged just previously to the spark discharge, a severe strain in the ether is set up between and about them and when the air gap breaks down and the discharge occurs this ether strain is transformed into a train of electromagnetic waves which spread outward in all directions. The resonator is a device for detecting the presence of these electromagnetic waves. The one used by Hertz in these first crude experiments consisted of a stout copper wire circle of twelve inches radius with a very small spark gap in the circle. Now when he held this circle parallel to the spark gap of the induction coil and its plates, he obtained minute sparks across the resonator gap of the circle. A simple thing to do it may seem, and yet in this discovery lay the germ of all the marvelous wireless work that has followed.

Hertz soon found that he could tune his resonator. He made the spark gap adjustable and by changing the width of it discovered that there was a certain length at which the spark was brightest. He also found that there was a certain position of the plane of the resonator in which the result was best and therefore concluded that the ether waves traveled in a particular direction. This tuning of

the resonator is exactly similar to the sympathetic vibrations observed in musical instruments of the same pitch and had a tremendous influence on the later development of radio communication.

By placing his oscillator, as he called the induction coil and plates, and his resonator in parabolic mirrors he was able to prove that these electromagnetic waves could be reflected, refracted and polarized and therefore possessed all the properties of light and radiant heat waves. By a method exactly similar to that by which we measure the length of a sound wave, Hertz was able to measure the length of the ether waves finding them to be about 100 feet and their velocity therefore 186,000 miles per second, or identical with that of light. No further proof was necessary to establish the fact that light waves are also electromagnetic vibrations, differing from electrical vibrations simply in wave length. It was a brilliant discovery and led to magnificent results.

Even earlier than this Sir Oliver Lodge had performed an experiment with Leyden jars very similar to that of Hertz. A Leyden jar is a condenser made by coating a glass jar both inside and out with tin foil for about two-thirds the way from the bottom to the top and covering with an insulator through which is thrust a metal rod in contact with the inside foil and terminating in a knob above. Sir Oliver Lodge arranged two jars as shown in the diagram and connected one of them to an induction coil or the terminals of a static machine. Between the knobs of this jar sparks would pass and the electromagnetic waves striking upon the other jar produced small sparks at its terminals. This was possible, however, only when the two jars were tuned to the same pitch and to accomplish this a sliding contact CD was provided for the

rectangular conductor of the second jar. By sliding this along until the areas of the two sets of conducting surfaces were the same the point of "syntony" was reached and the two circuits were in tune. But it did not occur to

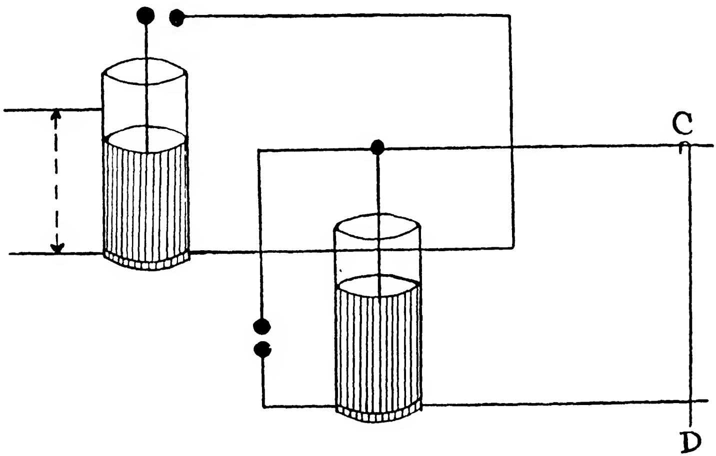


FIG. 23.—Apparatus used by Sir Oliver Lodge.

Lodge that this simple experiment might be made the basis of wireless telegraphy and as he said himself later he did not see the necessity for wireless communication with wire telegraphy and telephony developed to so high a state of perfection.

In 1890, Professor E. Branly of Paris discovered, or rather rediscovered, the principle of the coherer, a sensitive detector of electric waves, without which the early practical development of wireless work would have been impossible. Professor Branly found that if a small glass tube loosely filled with metal filings were placed in circuit with a battery and electric bell it would not conduct sufficient

current to ring the bell. When, however, Hertzian waves fell upon the metal particles he found that they would cohere, or arrange themselves in a path of such small resistance as to allow the current to flow and ring the bell. This supplied just the missing link necessary to further progress. One of the first to utilize this new discovery was Professor A. Popoff of Russia. He made a coherer as resonator, running a wire leading from the filings high into the air and was able to detect the electromagnetic waves from lightning discharges.

Marconi and His Work.—Much preliminary work had now been done and the stage was set for the man of genius who combining the vision of the seer with the mechanical skill of a master workman should be able to bring his dreams to pass. Such a man, or rather boy, for such he was at that time, was Guglielmo Marconi. Marconi, the youth, saw the great possibilities of wireless communication and with the clear insight of genius perceived that the discovery of the Hertzian waves opened a door to their realization.

Marconi was born on April 25, 1874, at Villa Griffone near Bologna, Italy. His father was an Italian and his mother an Irishwoman. He attended both Italian and English schools, learning to speak both languages fluently. He early showed great aptitude for scientific pursuits and under his Italian master, Professor Righi, an investigator of some note, he learned of the Hertzian waves and what had been done up to that time. Becoming impatient with the slow progress made by the great scientists of the world in their well equipped laboratories, Marconi set out to experiment for himself. This was about 1894 and we must remember that at that time no real practical work with a view to telegraphing through the ether had been

done. The so-called methods of Trowbridge, Edison and Preece had been based upon conduction and induction, making use of the earth or water and had not called into full service the electromagnetic waves of Hertz. But Marconi with only a knowledge of the Hertzian discovery began a work or true research, the brilliant results of which very shortly startled the world.

Marconi began his experiments on his father's farm. He employed an induction coil and oscillator similar to the one used by Hertz but he made a new departure which proved to be his first great contribution to the new science of radio communication. This consisted in grounding one terminal of the induction coil and in connecting the other to a wire which stretched upward into the air. By so doing Marconi increased many times the capacity of his oscillator to produce and radiate electromagnetic waves. He also used a similar aerial for receiver and in a short time was able to transmit signals corresponding to the Morse code across a distance of a few hundred feet.

He soon saw that the critical part of his apparatus was the receiver and very shortly adopted the Branly coherer. He made important improvements in this and increased its sensitiveness wonderfully. For the metal filings he used nickel powder mixed with a small quantity of silver. These he inserted between silver plugs in a small glass tube. The plugs were placed about a millimeter apart and platinum wires were soldered to them. It required a good deal of experimenting to determine just the right quantity of powder and the proper pressure and distance between the plugs in order to secure the required degree of sensitiveness. Now Branly had discovered that after the filings had been made to cohere by the passage of a train of electromagnetic waves they could be placed in

the non-conducting state again by tapping the glass tube. Therefore, Marconi devised an automatic tapper or decoherer, as it was called, which after the passage of each wave train gave the tube a light blow and jarred apart

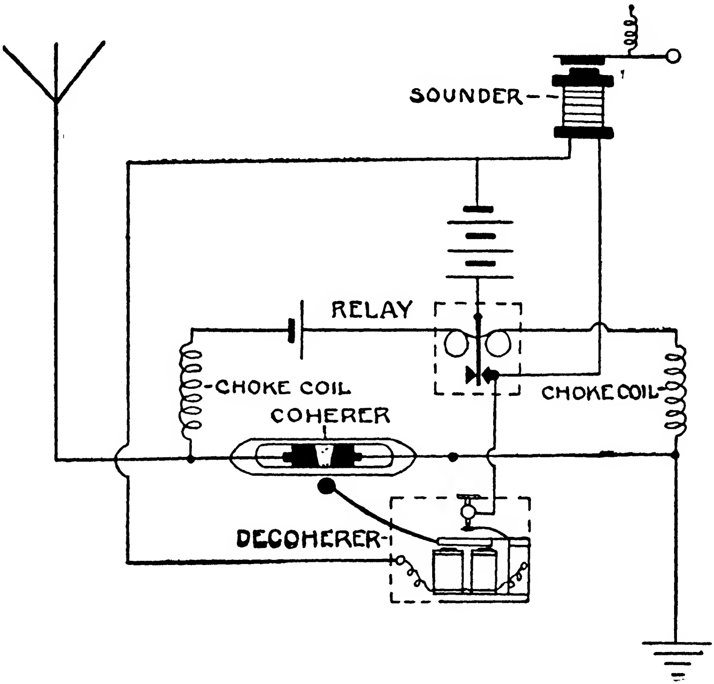


FIG. 24.—Marconi's early receiving set.

the metal filings. In the receiving aerial Marconi inserted his coherer and in circuit with it a battery and relay which just as in the ordinary telegraph receiving set makes and breaks a local circuit which operates the heavy sounder. When Marconi pressed the key of his transmitter a spark

jumped across the gap of the induction coil and the train of electromagnetic waves proceeding from the sending aerial and moving through the ether were caught by the receiving aerial, passed through the coherer and down to the earth. This passage of the wave train through the

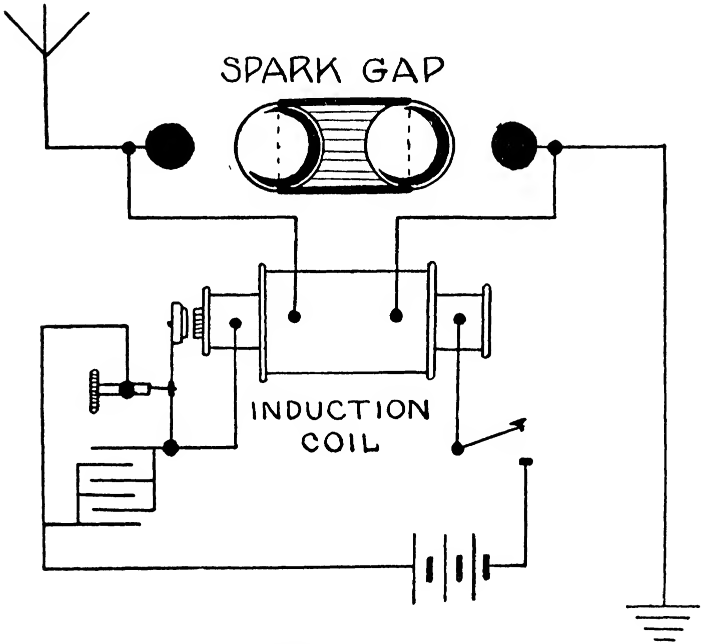


FIG. 25.—The Marconi sending apparatus.

coherer made a conductor of the metal filings thus closing the relay circuit which in turn operated the local circuit and sounder. At the same time current flowing through a shunt circuit caused the decoherer to disarrange the metal filings and thus break the relay and local circuits. By holding the transmitter key for short or long periods the

resulting wave trains could be made correspondingly short or long and to give rise to the dots and dashes of the Morse code. Only a small portion of the ether waves sent out by the transmitter aerial were caught by the receiving aerial and were therefore too weak to operate a receiving mechanism themselves. The early transmitting and receiving outfits of Marconi will become clear from a consideration of the accompanying figures.

One important discovery made by Marconi early in his work was that the height of the aerial greatly affected the range of his sending station, the higher the aerial being the greater the range. He continued to experiment and improve his apparatus until in 1896 he was sending messages over distances of several miles. In that year he went to England with his wireless system, submitting it to Sir William Preece, who was at that time in charge of the Postal Telegraph system of England. Preece, who had also experimented along these same lines, received him cordially and gave him every assistance possible. A short line set up in the Post Office Building in London worked with perfect success and stations two miles apart were erected outside the city with equally good results. In the following year Marconi set up a station on the Isle of Wight and maintained communication with the mainland. Returning to Italy he secured the use of a warship for his tests and sent messages for considerable distances from ship to shore. In 1898, his wireless outfit was used to send news of the annual Kingstown regatta to a Dublin paper, the apparatus being placed on board a steamer which followed the yachts.

Very soon Marconi had established wireless communication across the Channel between England and France. Channel steamers were equipped with wireless and its

utility was quickly established by the service one of these boats was able to render through its aid to a ship in distress off a rocky portion of the North Sea coast. Being unable to go in safety to the rescue of the crew of the imperiled ship a wireless message to the land station brought timely assistance. Light-ships were supplied with wireless equipment and its great value in this field was early recognized. The British Admirality equipped its battleships with wireless outfits and in a sham battle completely demonstrated its great usefulness in naval warfare.

But the greatest triumph was yet to come. Marconi was able to signal over the greater part of eastern Europe and his next objective was to transmit messages across the Atlantic. It is interesting to note that in this early pioneer work Marconi had not been compelled as most inventors are to struggle against poverty and adversity. Just as in the case of Morse and Bell there were plenty to ridicule his early claims, but one success so rapidly followed another that the scoffers did not have long to enjoy their sacred prerogatives. His father supplied the funds for his early work and after demonstrating its great utility the British Admirality paid him $100,000 for the use of his invention in the navy. Other countries paid him similar royalties and there were left the tremendous commercial possibilities which have been a still richer reward.

For the purpose of signaling across the Atlantic Marconi established the famous Poldhu Station at Cornwall, England. Instead of using a single aerial or antenna, as he called it, he erected a large number of tall masts and connected them with wires strung from mast to mast. The batteries and induction coil which had served as transmitter in all his early work were replaced with powerful dynamos and a huge transformer. In December, 1901, Marconi

crossed to America and at St. Johns, Newfoundland, with immense kites for an aerial he waited in perfect confidence for the prearranged signal. It had been agreed before leaving Cornwall that at intervals of three minutes between the hours of three o'clock and six o'clock, English time, the Poldhu station should send three dots, the signal for the letter S in the Morse code. Because of its greater sensitiveness, Marconi substituted a telephone receiver for the relay and sounder and with this at his ear waited patiently on Dec. 12th for the signal. He did not have long to wait for presently three unmistakable clicks sounded in the receiver and Marconi knew that transatlantic wireless was not merely a possibility but a demonstrated fact.

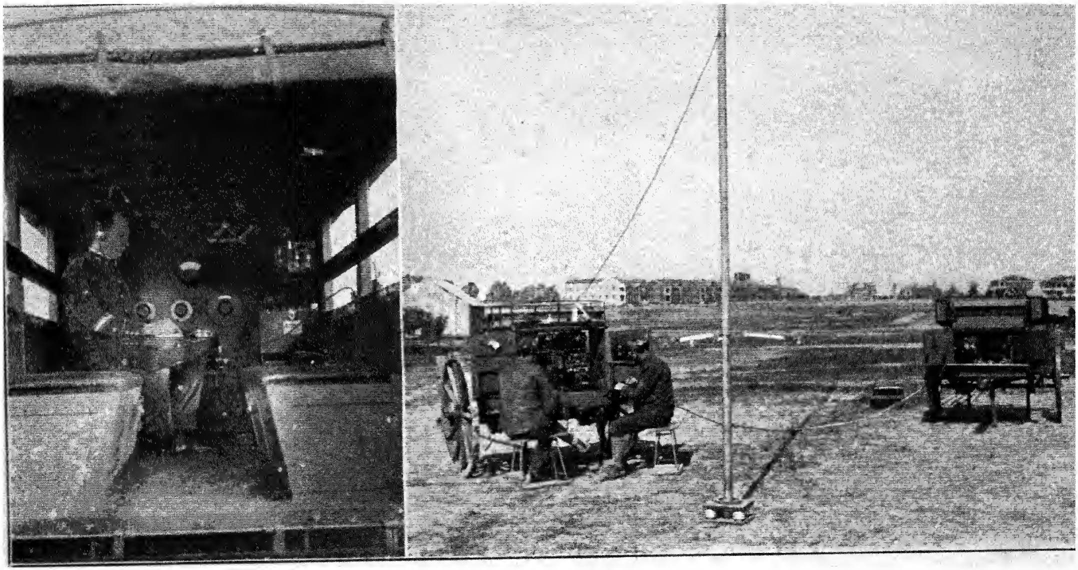
Marconi returned to England and a little later in a second trip to America on the steamship *Philadelphia* kept in communication with the Poldhu station for a distance of 150 miles and was able to receive messages at a distance of 2000 miles. Wireless telegraphy was now firmly established and the time had arrived for expansion and commercial development.

In the mean time experimenters in every country had been at work and naval and merchant vessels were being equipped with wireless apparatus. Ship-to-ship and ship-to-shore communication became the fad of the hour. Wireless messages from transatlantic liners for two days after leaving port were regularly received. As the telephone had banished the by-places of the continent so the new-born wireless was destined to banish the isolation of the sea. Surely the world is shriveling in size and even now seems like a pigmy in comparison to the great unknown that Columbus set out to explore.

Wireless telegraphy rapidly demonstrated its usefulness. The sea is its pre-eminent domain and here it became

supreme. Numerous rescues of shipwrecked vessels, especially in the cases of the *Republic* in 1903, and later of the *Titanic*, proved its worth. The United States Government as well as foreign governments early passed laws requiring wireless equipment on all liners engaged in passenger service. The next great contribution of Marconi was his system of tuning wireless transmitters and receivers to a definite pitch so that no matter how many messages might be traversing the ether at the same time a given receiving set would respond only to waves of a certain length. The method by which this is done will be explained later, but it can be clearly seen that without such means of tuning every receiver would record a perfect jumble of signals and intelligible communication would be impossible.

Later Development.—A large number of inventors and scientists have since contributed to the development of wireless receiving and sending mechanisms. The whole practice of wireless has been revolutionized. Adjustable aerials have replaced fixed aerials. For the induction coil and battery circuit have been substituted the high frequency alternating current generator and transformer. Condensers and oscillation transformers have been added to the transmitting apparatus. In the receiving set the coherer and Morse instruments have given way to a more sensitive type of detector and the telephone receiver. Amplifiers for the feeble electromagnetic waves which distant aerials are able to gather have increased enormously the range of transmission and reception. The dots and dashes similar to those of the Morse instrument are now produced in the telephone receiver as a series of musical notes of short and long duration. Among American inventors who have contributed much to the development of wireless



By courtesy of Scientific American.

A naval operator receiving a wireless message and a radio military field station.

systems are Dr. Lee DeForest and Professor Fessenden, both of whom are world leaders in the science of wireless communication.

The wildest flights of fancy of the early pioneers have been more than realized in the wonderful applications of wireless telegraphy in the commercial, naval and military affairs of all the great nations of the earth. As already stated its use is indispensable on ship board and so numerous and powerful are shore stations that at no time during an ocean voyage are travelers out of touch with land. But it is in the great European War that wireless has demonstrated its wide range of usefulness. Naval ships have been controlled by wireless, including the German U-boats. Millions of dollars and thousands of lives have been saved by the system of radio communication adopted by all nations. Aircraft have been equipped with wireless sets making use of the metal frame for a ground and a trailing wire paid out from a reel for an aerial. These sets have a sending range of from 30 to 35 miles, but because of the great noise and vibration of the engine, receiving is extremely difficult. Aside from scouting their chief use is to direct artillery fire. The Zeppelins are able to carry more powerful apparatus having a range of from 60 to 120 miles.

The armies in the field carry portable wireless outfits. These are usually mounted on two wagons, one of which carries the generator and the other the wireless apparatus. In rough countries the outfit is carried on mule-back. Within five minutes the aerial can be erected and signalling begun. Wireless is employed very largely for trench warfare communication.

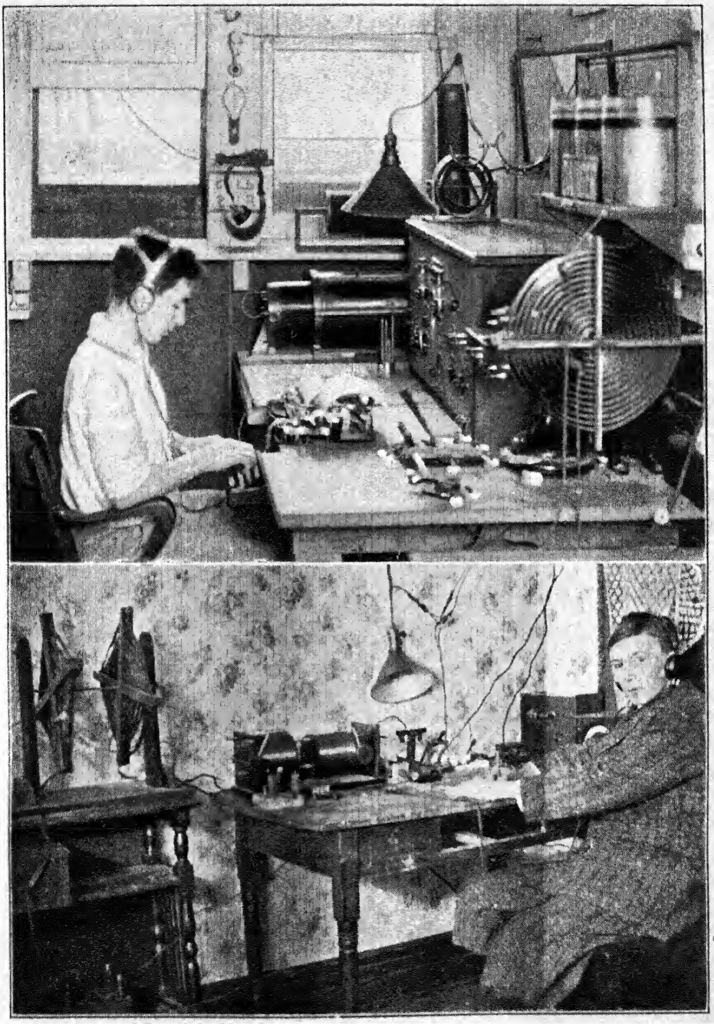
Early in the war when Germany was cut off from the outside world she established wireless communication and from the powerful station at Nauen, near Berlin, has sent

out her messages to the entire neutral and belligerent world. No nation could censor them and her own version of the war could be given the utmost publicity. The Allied powers kept in communication with each other and from the powerful Eifel Tower station in Paris the Western front was kept in touch with Russia and the East.

At the opening of the great War in 1914, there were scattered throughout the world about 700 land stations and 4500 ship stations. Since then these numbers have been greatly increased and when the war is over there will be put into operation a chain of wireless stations encircling the globe. These stations will have ranges of thousands of miles and their object will be commercial service.

Already there are other fields of usefulness for wireless as in the city police service, the government forestry service, the weather bureau, accurate time signalling, in isolated mining regions, the fisheries and in the collection and transmission of news. What the future holds no man dare prophecy for the dreams of yesterday are eclipsed by the achievements of today. Certainly the sphere of usefulness for radio transmission will ever widen and the dream of transmitting energy in vast quantities by means of electromagnetic waves may, indeed, come true. This is surely the age of dreamers and they have a wonderful faculty for bringing the "impossible" to pass.

But we must not forget to pay tribute to the very important part which the American boy has played in the development of wireless service. Wireless appealed to the imagination and practical instincts of boys everywhere and wireless amateur stations sprung up in every town and hamlet from Maine to California. Boys built their own apparatus and constructed their stations. These stations



By courtesy of Electrical Experimenter.

Amateur wireless laboratories.

have performed very useful work on numerous occasions. In 1913, when the Middle Western States were swept by flood and all telegraph and telephone lines were cut these amateur wireless stations preserved communication with the outside world and assisted in the rescue work. The American Radio Relay League comprising 4000 members, 1000 of whom were experts, established transcontinental service starting at Valley Stream, Long Island, and following a path which included Lima, Ohio, Chicago, Dallas, Texas, San Diego and Los Angeles. These amateurs have given much assistance to naval and commercial operators in receiving long distance messages.

Although these stations have been dismantled for the period of the war, the amateur operators have proved a great asset to the nation and in large numbers have been recruited into the national service. England, unlike the United States, was without amateurs at the beginning of the war and was compelled to train a large body of wireless men. Although now suffering an eclipse, the day of the amateur is bound to return and the American boy can once more satisfy his love for the wireless art.

CHAPTER VI

THE THEORY AND PRACTICE OF WIRELESS

As has already been shown the success of wireless telegraphy depends upon the setting up of electromagnetic waves in the ether of space. Before we go further it may be well to inquire what we mean when we speak of the ether. It is known that outside of the earth's atmosphere, which extends at most but a few hundred miles above the surface, there exists a vacuum inconceivably better than any ever produced by mechanical means. And yet light and radiant heat energy travel ninety-three millions of miles from the sun to the earth supplying all the energy for the planet upon which we live. Now it is unthinkable that light and heat should travel this distance, or any distance for that matter, without some transmitting medium and therefore we assume that such a medium, which we call the ether, exists. An incandescent lamp bulb contains a vacuum and yet light and heat travel from the glowing filament through it and affect our senses of sight and touch. We must assume that the vacuum is filled with something that transmits this energy and this something we call ether. Likewise between us and the distant stars must stretch for infinite distances this intangible, weightless, yet all pervading fluid.

It must be assumed that the reader of this book has an elementary knowledge of electricity and magnetism and if not he is referred to any standard text for this information.

Wireless telegraphy may be divided into four operations:

1. The setting up of electrical oscillations.
2. The transformation of these electrical oscillations into electromagnetic waves.
3. The transformation of the electromagnetic waves back into electrical oscillations.
4. The detection of these oscillations.

The first two sets of operations are performed by the transmitter and the second two by the receiving mechanism of a wireless outfit.

As previously indicated electrical oscillations are set up by the lightning-like discharge between the secondary terminals of an induction coil or by the discharge of a condenser and also by the discharge from the secondary of a transformer. These oscillations at the same time impart electromagnetic vibrations to the surrounding ether which traveling with the velocity of light are caught by some distant receiving aerial and there set up in the receiving circuits oscillations which can be detected in a telephone receiver. This setting up of electromagnetic vibrations in the great ocean of ether is very similar to the production of water waves by the tossing of a pebble into a pond. In each case waves are produced which traveling outward in ever widening circles dissipate their energy as they go and finally disappear. A floating chip catching a small portion of the energy in the water waves rises and falls thus serving as a detector and performing the same function as the aerial and receiving circuits for electromagnetic waves.

The Induction Coil.—Although the induction coil is no longer used for wireless transmission, wherever alternating current is available, its use in the past has been so important and it is still used so frequently in the absence of

alternating current that a brief explanation of its construction and operation is desirable.

The construction of an induction coil is shown in the accompanying diagram. Its essential parts are a core made up of soft iron wires, a primary coil, a secondary

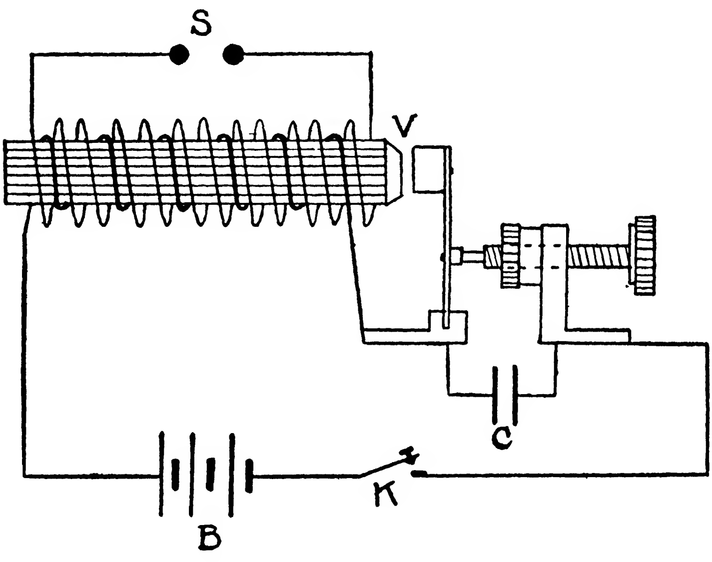


FIG. 26.—An induction coil.

coil, an interrupter and a condenser. The primary coil consists of a comparatively few turns of rather coarse insulated copper wire wound upon the soft iron core. The secondary overlies the primary, being wound upon a hollow spool and consisting of very many turns of fine insulated wire the ends of which terminate in large brass knobs with a spark gap between. The interrupter shown here is of the magnetic vibrator type with a platinum contact point

resting against a similar point on the contact screw. The condenser is made up of two sets of tin-foil plates insulated from each other, one set being connected to one side of the make and break gap of the primary circuit and the other set to the opposite side.

The action of the induction coil is as follows: The primary is connected with a set of batteries and as the current flows through the circuit the soft iron core becomes an electro-magnet drawing over the soft iron vibrator and thus breaking the circuit at the platinum contact points. This breaking of the circuit demagnetizes the soft iron core and the vibrator springs back making the circuit and repeating the operation. Thus the making and breaking of the primary circuit occurs at a rapid rate, causing the lines of magnetic force surrounding the primary coil alternately to cut out across the turns of the secondary and then to surge inward cutting back across them in the opposite direction. Now whenever lines of force are made to cut across a conductor an electromotive force or difference of electrical potential is induced in that conductor. The intensity of this electromotive force is proportional to the rate of cutting of the lines of force, and therefore will depend upon the number of lines of force, the relative number of turns of wire on the secondary and the rate at which the field is built up or dies down. When the difference of potential between these terminals becomes sufficiently high a discharge will occur across the spark gap and a set of electrical oscillations will be set up.

Another factor which will explain the use of the condenser must be taken into account. It will be seen that as the primary field builds up, the lines of force surge outward not only across the secondary but across the primary as well. And therefore from the law of induced currents a

self induced current will be set up in the primary itself which will oppose the battery current and prevent a rapid building up and surging outward of the lines of force. Since the electromotive force of the secondary depends upon the rate of cutting of the lines of force, it will be seen that the self induction on the make tends to prevent a rapid cutting and results in a low electromotive force, so low that it is insufficient to puncture the air gap and produce a spark. As the lines surge inward, too, on the break a current is self induced in the primary but this time tending to prolong the battery current and to prevent a rapid dying down of the field. This self induced current manifests itself as a spark at the contact points and as long as this spark passes the primary current continues to flow. Now in order to overcome this effect of self induction on the break a condenser is placed across the contact points and the high E. M. F. of the self induced current, first charges the plates of the condenser instead of producing the spark and then, discharging back through the primary in the opposite direction to which the battery current is flowing, destroys this current instantaneously and produces a very rapid cutting of the lines of force. Therefore a discharge of the secondary occurs only on the break. This discharge as will be shown later is oscillatory and gives rise to electromagnetic waves.

The Condenser.—The construction of the Leyden jar form of condenser will become apparent from the accompanying figure. It is easily made and much used in wireless work. Such a condenser may be charged in the simplest manner by placing the brass knob in connection with one terminal of an induction coil or static machine, say the negative, and taking hold of the outside tinfoil with the hand. As the induction coil or static machine is operated,

negatively charged particles called electrons pass onto the knob and streaming through the brass rod spread over the inner tinfoil, at the same time repelling an equal number of electrons from the outer tinfoil through the body of the operator to the ground. Thus the inner surface of the glass jar in contact with the tinfoil comes to be charged negatively and the outer surface positively, for the negative electrons repelled to the earth leave an excess of positive electricity on the outside of the jar.

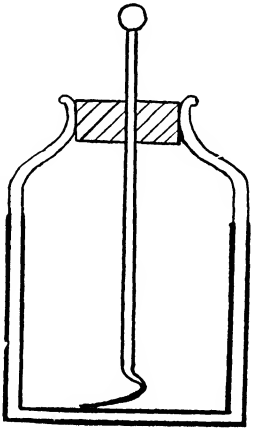


FIG. 27.—A Leyden jar.

If now the outer coating of tinfoil be brought close to the knob of the jar by means of a bent brass rod with an insulating handle, a powerful spark will pass. Although this discharge seems to be a single instantaneous spark it is really made of a large number of rapid oscillations, or to and fro surgings. The first passage of current serves to more than discharge the condenser coatings and, overshooting its mark, as it were, charges them in the opposite direction. A reverse discharge then occurs which again overshoots itself and the process is repeated over and over giving rise to a series of oscillations which growing weaker and weaker gradually die down or are "damped" out as is said. It is these electrical oscillations which give rise to the electromagnetic waves of wireless telegraphy.

A consideration of the action of a spiral spring to which is attached a weight may help to make more clear the matter of electrical oscillations and also to show the rela-

tion and meaning of two very important factors in all oscillatory circuits, namely inductance and capacity.

If we suspend the spring and weight as shown and charge the system, so to speak, by pulling the weight down and then discharge it by letting go, we shall get a series of reactions very similar to those occurring during the charging and discharging of a Leyden jar. The weight does not simply return to its starting point and stop but its inertia carries it by this point and it oscillates up and down, the oscillations gradually dying down until the weight is again in its original position. Now there are two forces that are governing this oscillatory motion, the springiness or elasticity of the spring and the inertia of the system. By inertia we mean the opposition offered by the weight either to starting the motion from rest or to stopping the motion when the weight in its upward movement reaches the middle point.

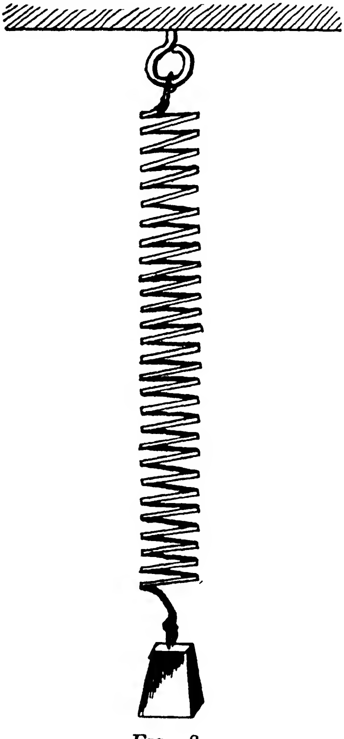


FIG. 28.

Now what is the effect of each of these factors on the resistance of the system and the number of oscillations? If we gradually increase the weight we increase the resist-

ance to the motion, and the amplitude, or distance moved through, becomes less and the number of oscillations fewer. That is, an increase of the inertia "damps" out the oscillations and it can readily be seen that if we make the weight great enough there will be no oscillations at all. When the weight is drawn down it will simply come back to its position of rest and stop. To increase the elasticity of the spring, however, increases the amplitude of the movement, lessens the resistance and increases the number of oscillations. Thus it will be seen that the elasticity effect tends to neutralize the inertia effect so far as the number and amplitude of the oscillations is concerned.

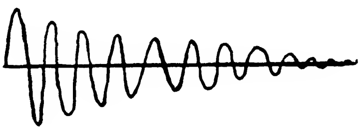


FIG. 29.

If we could attach a pencil at right angles to the moving weight and allow it to trace a record of the oscillations on a moving sheet of paper the result would be as shown in Fig. 29. This gradual decrease of the wave movement is called damping.

There are other factors which affect the resistance to the oscillatory motion. In the case of the spring and weight some energy is imparted to the air and if we should make the system vibrate in water or thick syrup the amount of energy imparted to the surrounding medium would be still greater. We might also cause this spring system to impart energy to another spring system, setting it into vibration. All of these factors would have the effect of additional resistance and decrease the amplitude and number of oscillations.

Now let us make a comparison between our mechanical spring system and the oscillatory discharge circuit of a Leyden jar. At the start let us fix clearly in mind that

the capacity effect of an electrical circuit corresponds to the elasticity of the spring and the inductance effect to the inertia of the system. A consideration of the self induction in the primary circuit of an induction coil, will make clear the meaning of inductance. Inductance opposes either the setting up or dying down of an electrical current. To give another mechanical analogy for capacity, we may say that it is the same as the number of cubic feet of air that must be forced into a tank to raise its pressure one pound per square inch. Capacity tends to increase the flow of electricity, inductance chokes it back. The potential energy stored up in the elasticity of the air in the air dome of a force pump would be capacity, while the friction of the pipes and the inertia of the water would be inductance.

As already explained the discharge of a Leyden jar is oscillatory. Just as the weight and spring do not stop at the middle point of the upward swing but move by it, charging the system in the opposite direction and continuing to charge and discharge it alternately until the resistance damps out the oscillations, so the discharge of a Leyden jar does not stop at the middle point, so to speak, but charges the condenser surfaces in the opposite direction and the process continues until the oscillations are damped out as before. At the same time the spark discharge imparts energy to the surrounding ether in the form of electromagnetic waves and this corresponds to the energy imparted to the air or other medium surrounding our spring system. This is the real function of a wireless transmitting set as we shall see. The greater the capacity, the greater the number of oscillations. But any resistance such as that of the air in the spark gap will decrease the number of oscillations. The amount of in-

ductance in a simple Leyden jar is very small but the exact relation of capacity and inductance in a wireless oscillatory discharge circuit will be fully explained a little later.

The capacity of a condenser will depend upon its size. There are other forms of condensers than the Leyden jar, the construction of which will follow later. Condensers

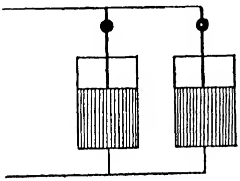


FIG. 30.

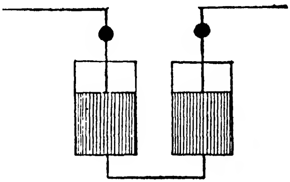


FIG. 31.

may be grouped in parallel as shown in Fig. 30 or in series as shown in Fig. 31. In the parallel grouping the total capacity is the sum of the separate capacities of the condensers, while if in series it is equal to the sum of the reciprocals of the separate capacities. Therefore to increase the capacity of a circuit place condensers in parallel and to decrease it place them in series.

Any circuit possesses capacity and inductance and their importance will become apparent when we consider the frequency of oscillations and the tuning of circuits into resonance with each other.

The Transformer.—For the purpose of charging condensers and producing the electrical oscillations for wireless work the transformer is now used in all commercial work and for amateur work wherever possible. It is in principle identical with the induction coil but for the direct current and interrupter of the primary circuit an alternating current of from 60 to 500 cycles per second is substituted. Every dynamo current as generated in the armature is

alternating and may be taken off in the external circuit either as alternating or direct. By a cycle is meant the building up of the E. M. F. from zero to a maximum, its dying down to zero, its building up to a maximum in the opposite direction and its dying back to zero again. This cycle of changes takes place during one revolution of the single loop armature of a two-pole dynamo. It will be seen then that in each cycle there are two reversals of current and therefore a 60 cycle current reverses itself at the rate of 120 times per second and a 500 cycle current makes 1000 reversals per second.

A transformer consists essentially of a soft iron ring with two windings, a primary and a secondary. Trans-

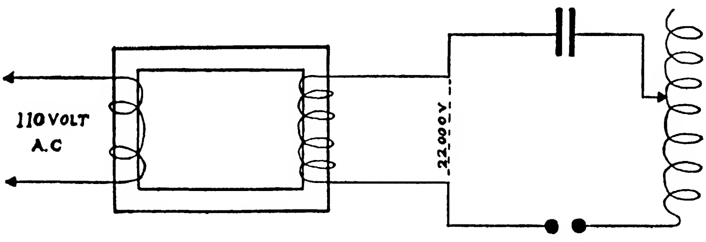


FIG. 32.—A transformer.

formers are of two general types, step up and step down. One raises the voltage and decreases the current while the other produces the opposite effect. It is the step up transformer that is used for wireless transmission and the principle of its construction is shown in the diagram. Just as in the induction coil when the current in the primary winding passes in one direction the lines of force surge outward, cutting across the secondary winding and as the current reverses itself the lines of force cut the secondary in the opposite direction. Also as in the induction coil

this induces a high E. M. F. in the secondary producing a discharge across the spark gap and generating a train of electrical oscillations.

Aerials—The simple oscillator of Hertz or the discharge from a Leyden jar is unable to use for the production of electromagnetic waves very much of the energy in the spark discharge. Consequently the waves emitted are very feeble and very short. They carry but a short distance and are much interfered with by obstructions such as buildings, forests and hills. Marconi early found that he could greatly increase the distance of transmission by attaching to one terminal of the spark gap of his induction coil a ground wire and to the other terminal a wire leading high into the air and having a metallic plate fastened to its upper end. This not only lengthened the wave but increased very much the capacity of his transmitter. The aerial and the earth then become a huge condenser, one being charged positively and the other negatively. This increased capacity increased the quantity of the electrostatic charge that could be stored up for the production of the oscillatory spark and also increased many times the amount of energy available for the generation of electromagnetic waves.

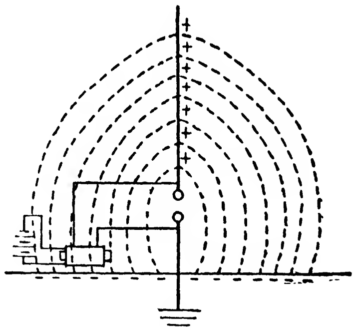


FIG. 33.

The conditions just previously to the discharge are shown in Fig. 33. Lines of electric strain are set up in the ether and pass from the antenna, as the aerial is called,

to the earth repelling each other outward into a pear shape. When the difference of potential becomes great enough, the insulation of the spark gap breaks down, the spark discharge occurs and the upper ends of the lines of electric strain rush down to meet the lower ends as shown in Fig. 34. This produces a train of electromagnetic waves which ra-

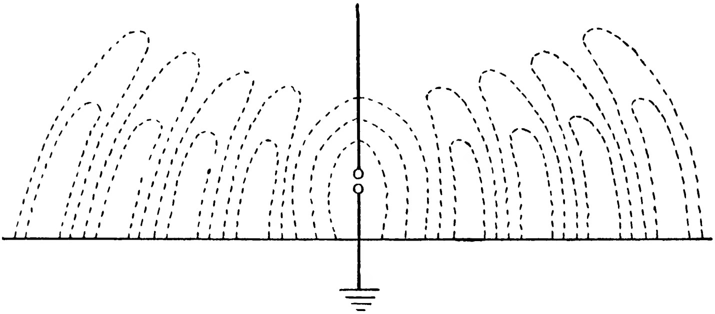


FIG. 34.

diate outward with the velocity of light and are the waves which make wireless telegraphy possible. Just as in the case of the Leyden jar this discharge is oscillatory and a series of wave trains are sent off. The greater part of the total energy of the discharge is used in the spark gap, a portion heats the antenna and the remainder generates the electromagnetic waves.

These waves in the form of a series of half loops with their feet on the ground move outward over the earth and sea. The sea is a better conductor than land and moist earth better than dry earth. Therefore transmission is better over sea than over land and better over a region of plentiful rainfall than over a desert.

The length of the wave radiated off is approximately four times the length of the aerial and the effective length

of this aerial may be increased by introducing at the bottom of it a spiral coil of wire called an inductance coil. And here we meet inductance again. Inductance therefore decreases the frequency or rate of oscillation and increases the wave length. An increase of capacity will also decrease the rate of oscillation and lengthen the wave. Therefore it will be seen that the wave length, so important in tuning wireless circuits into resonance, depends upon the two factors of capacity and inductance. Wireless waves vary in length from 200 meters and less, used in amateur work, to 1600 meters and sometimes more for commercial work. The two standard wave lengths for commercial work are 300 and 600 meters. A meter is a little more than 3 feet, or 39.37 inches.

Marconi soon found that he could increase the capacity of his aerial much more effectively by using several parallel antennae joined above and below than by using a metal plate. Several of the more common forms are shown in Fig. 35. The chief purpose of any aerial is to increase the amount of energy that can be stored and radiated.

Electrical Resonance.—There is no more important factor in practical wireless work than the matter of resonance and tuning. In the transmitting set the oscillation transformer must be tuned into resonance with the aerial circuit and in the receiving set the aerial circuit must be tuned to resonance with the closed oscillation circuit in which is placed the detector and telephone receiver.

An illustration from the properties of musical instruments will make clear what we mean by resonance. It will be recalled that Bell caught the idea of a musical telegraph from the fact that when he sang a particular note close to the keys of a piano, the string of the same pitch would answer him. In like manner if we set a tuning

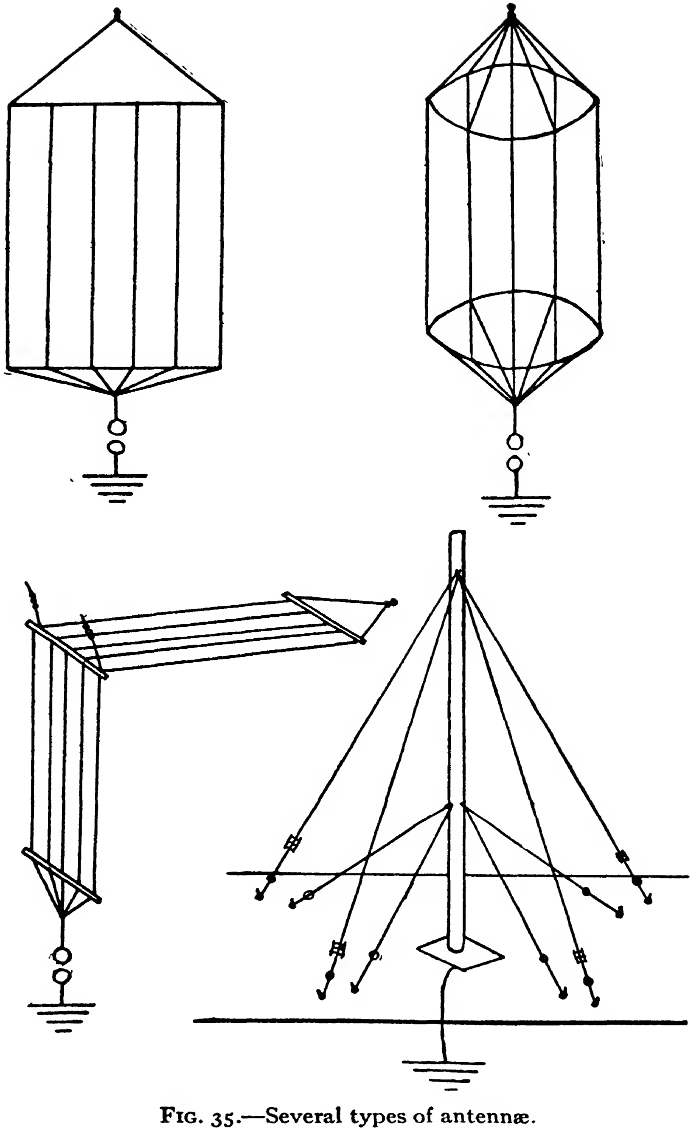


FIG. 35.—Several types of antennæ.

fork into vibration and place near to it another fork of the same pitch, or rate of vibration, the second fork will be set to vibrating. This can be detected by touching the first fork so as to stop its vibration when the second fork will be found to be emitting a clearly audible note. A tuning fork sends forth a definite number of waves per second, each wave having a definite length. In like manner an electrical oscillation circuit sends out a definite number of waves per second, each wave having a definite length. Electrical oscillation circuits also have a definite pitch and can be tuned into sympathy with each other just the same as two tuning forks can.

As we have seen in the case of an aerial the rate of vibration of an oscillation circuit depends upon two factors, capacity and inductance. An increase of either decreases the number of oscillations in a second and increases the wave length. Now if as with our tuning forks one oscillation circuit is to be set into sympathetic vibration with another the values of the capacity and inductance in each circuit must be such as to make the natural vibration rates of the two circuits the same. These values do not have to be the same in each circuit but their products must be the same.. Just as we can have two sets of factors each of which will produce 12, so we may have two sets of capacity and inductance each of which will give the same oscillation frequency to its circuit.

Let us consider the two oscillation circuits shown in Fig. 36. This is the conventional way of representing the "coupling" of two such circuits. The circuit at the left is the primary and that at the right the secondary. The condenser is at C, the inductance coil at L and the spark gap at S. A hot wire ammeter is placed in the secondary circuit at A so as to determine when the maximum effect

is produced and the two circuits are most closely in tune. The capacity in each circuit is a fixed quantity but the amount of inductance may be varied by the movable contacts. Across the spark gap of the primary circuit is connected an induction coil or transformer. As the primary

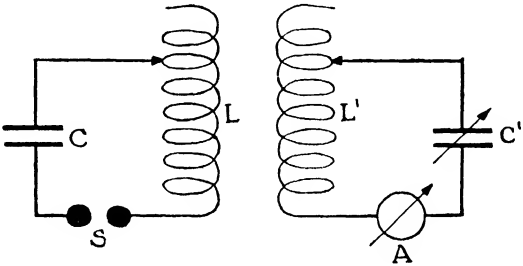


FIG. 36.

circuit becomes charged and the spark discharge occurs at S the electromagnetic waves sent off will induce oscillations in the secondary circuit giving a deflection of the ammeter needle. By moving the adjustable contact along the coil in the secondary circuit and thereby varying the inductance a point can be found where the deflection of the ammeter needle is greatest. This means that the two circuits are tuned into resonance with each other. This condition is reached when the product of the capacity and inductance in one case is equal to their product in the other. But if these products differ very much there will be little or no oscillation in the secondary circuit.

Coupling of Circuits.—There are two general methods by which the antenna circuit may be set into oscillation. Either the spark gap of the transformer or induction coil may be placed directly in the antenna circuit as shown in Fig. 37, or the spark gap may form a part of a closed oscilla-

tion circuit inductively coupled to the antenna circuit as shown in Fig. 38. The former was the early method employed but the latter is now used almost altogether.

In the direct excitation of the antenna circuit the wave length to be radiated was regulated by a variable induct-

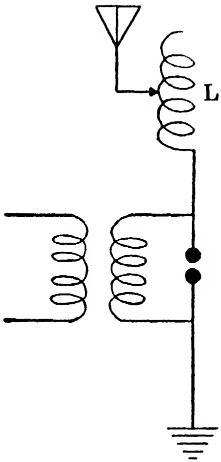


FIG. 37.

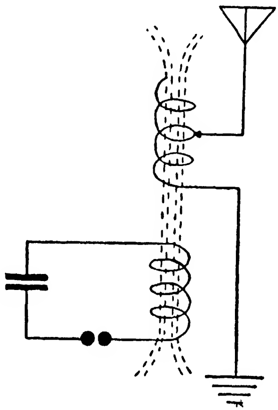


FIG. 38.

ance at L. A condenser is sometimes placed between the spark gap and the ground. Being in series with the oscillating circuit the condenser has the effect of diminishing the total capacity of the circuit and therefore increases the rate of oscillation and shortens the wave length.

In the method employing inductive coupling the closed oscillation and antenna circuits must be tuned into close resonance with each other. But another factor comes in here which is of considerable importance. These two circuits may be "closely" coupled or "loosely" coupled. The two coils here, the one in the closed circuit and the

one in the open antenna circuit, constitute the oscillation transformer. Now if the coil in the closed circuit is brought close to the coil in the open circuit or, perhaps, telescoping inside of it the coils are said to be *closely* coupled. But if these coils are drawn apart the coupling is *loose*. With the loose coupling not so much energy is transferred into the aerial circuit but on the other hand with the close coupling the oscillations of the antenna circuit will retransfer energy back into the primary circuit. This latter condition results not only in a loss of energy but, what is a greater disadvantage, it gives rise to the radiation of two waves from the aerial instead of one. A receiving station can be tuned to resonance with only one of these waves, the energy in the other wave being lost and besides needless interference with other radio stations is caused. A wave meter will show when the coupling is right. Close coupling usually results in what is called a "*broad wave*," while the loose coupling gives a "*sharp wave*." The *broad wave* is quickly damped out while the *sharp wave* does not damp out so quickly and requires "*sharp tuning*," that is, the receiving circuits must be closely adjusted to place them in resonance.

In this connection it may be said that what is called a quenched spark gap prevents the retransfer of energy from the aerial circuit back to the condenser circuit even with close coupling. This results in the radiation of a single wave. Such a spark gap consists of a number of heavy copper plates separated by thin mica washers placed in an iron rack and compressed by a pressure bolt. The spark gap between two adjacent plates is not over .01 inch.

The essential parts of a modern wireless transmitting set are shown in Fig. 39. They are:

1. Source of alternating current or storage batteries S.
2. Step up transformer or induction coil T.
3. A telegraph key K.
4. A battery of condensers C.
5. A spark gap G. (Quenched preferable.)

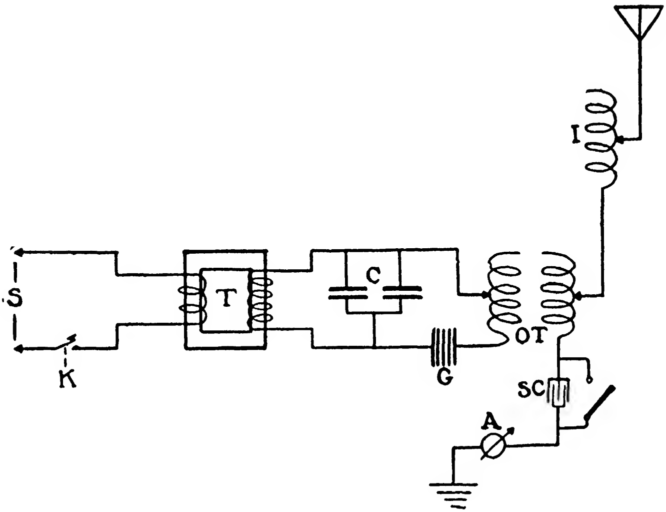


FIG. 39.—A wireless transmitting set.

6. Oscillation transformer O. T.
7. Hot wire ammeter A. for tuning transmitter.
8. Aerial tuning inductance I. (Not always used.)
9. A short wave condenser S. C. to shift from one wave length to another.

Receiving Apparatus.—The function of the receiving aerial is to absorb a portion of the energy from an advancing electromagnetic wave and transfer it to a receiving circuit. What the electromagnetic waves actually do is to induce

electrical oscillations in the receiving aerial which can be made to operate some sort of detecting device.

As we have seen Marconi used the coherer for this purpose but this has long since been superseded by more sensitive detectors. The telephone receiver is one of the most sensitive instruments for the detection of feeble currents and has come into universal use. It works best with an alternating current of from 300 to 500 cycles per second and therefore the unaided receiver cannot detect the very rapid oscillations of wireless currents. Very fortunately, however, it has been found that certain minerals such as iron pyrites, zincite, bornite, galena, silicon and carborundum have the property of allowing an electric current to flow through them in one direction but not in the opposite. Therefore if such a "*rectifier*" is placed in a circuit in which an oscillating electric current is flowing, this current will be converted into a direct or pulsating current.

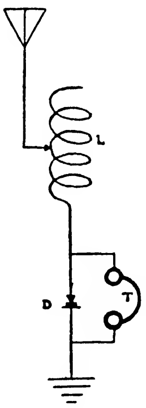


FIG. 40.

The simplest arrangement for a receiving set is shown Fig. 40. The detector is at D, the head telephone at T. The first requirement is to tune the open circuit of the receiving aerial into resonance with the open circuit of the distant transmitting aerial. This is done by varying the inductance in L, and frequently an adjustable condenser is also placed between the detector and the ground.

The action of the apparatus is as follows: A train of waves radiated from the transmitting aerial induces an alternating current of high frequency in the aerial receiving circuit. This current flows freely through the crystal detector in one direction, but is blocked in the opposite

direction. Suppose this current passes from the earth up through the detector placing a charge on the antenna. The return current being opposed this charge accumulates until the passage of the wave train, when it discharges to the earth through the head telephone, producing a musical note. There will be one note for each wave train, and it may be short or long representing a dot or a dash.

It is better, however, to place the detector in a local detector circuit and not in the antenna circuit because the detector hinders the free flow of oscillations and destroys somewhat the tuning qualities of the aerial circuit. The arrangement is shown in Fig. 41. The aerial circuit must now be tuned into resonance with the transmitting aerial and the detector circuit as well. A variable condenser is placed at C′ for tuning purposes. As before, the oscillations set up in the detector circuit flow through the detector in one direction charging the fixed condenser at C and at the end of each wave train discharge through the telephone producing a sound.

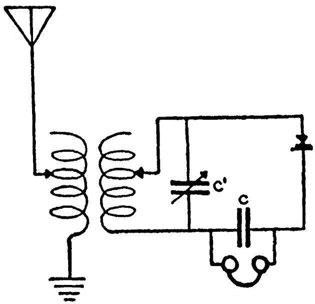


FIG. 41.

Another device employed in the receiving set is the potentiometer. It has been found that the application of a weak battery current to the crystal detector and head telephone increases to a very marked degree the intensity of the incoming signals. The potentiometer consists of a resistance connected with a battery as shown in Fig. 42. By sliding the movable contact K along the variable resistance a position can be found where the signals are most distinct.

Sending and Receiving.—When an operator wishes to send a message he first "listens in" to determine whether messages are passing which have the same wave length as he wishes to use. Finding that there are none he switches

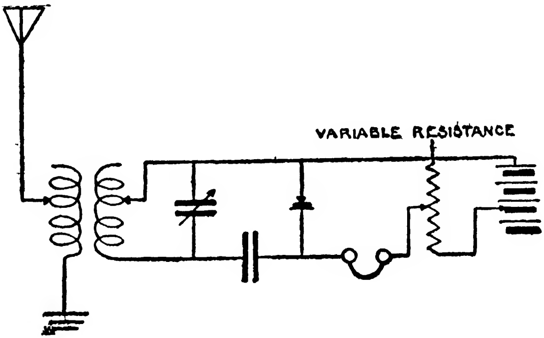


FIG. 42.

his transmitting apparatus to the aerial, and adjusts it to the proper wave length. The same aerial serves for both sending and receiving and at the same time that the sending set is switched in the receiving set is disconnected. He now presses the key and sends out the call letters of the station with which he wishes to get into communication, repeating the signals several times. He then switches out the transmitter and throws in the receiving set. If his call is answered he can begin to send at once.

Amateurs find it far more interesting to receive than to send, and a boy frequently starts with a receiving set only. The simplest sort of receiving set would consist of an aerial, a tuning-coil, fixed condenser, detector and receivers. With such a set installed the operator places the receivers on his ears and turns the adjustable thumb-screw on the detector until a distinct snapping sound is heard. A confusion of sounds will usually be heard from stations within

range of his instruments. In order to eliminate all but a single message and hear that distinctly, he moves the sliders along the tuning coil until clear musical notes tell him that he is in tune with some distant station and he is able to catch the message.

TWO WIRELESS EXPERIMENTS

1. The experiment of Sir Oliver Lodge, previously described, may easily be repeated by any boy. For a static machine substitute an induction coil, and in order to bring the inner tinfoil coating of the second Leyden jar close to the outer coating let a strip of tinfoil be brought over the edge of this jar from the inner coat to about one-sixteenth of an inch from the outer coat. For the loops coarse copper wire may be used. The loop of the jar connected to the induction coil will be closed and of fixed length. The other loop will be closed through a sliding contact so that the second Leyden jar may be tuned into resonance with the first. In the primary circuit of the induction coil insert a key or simply make and break the circuit by tapping the wires together. When the sliding contact has been adjusted so that the values of capacity and inductance in each circuit are the same, at each discharge of the first Leyden jar a small discharge will appear at the spark gap of the second. The Leyden jars should be of the same size and the two circuits parallel with each other.

In this simple experiment electrical oscillations are set up which produce electromagnetic waves, and in turn induce electrical oscillations in the second jar. The principle of tuning is also involved.

2. In a small glass tube about a quarter of an inch in diameter and three inches long place some fine brass or

nickel filings held in place by pieces of cork having a notch cut in the side of each. Through these notches thrust copper wires into the filings and connect them through two dry cells with an electric bell. If the bell begins to ring tap the tube containing the filings, jarring them apart so that the resistance will be so great that not enough current will flow to ring the bell. Then off at a little distance set an induction coil or transformer into operation and at the discharge and passage of the spark the bell will

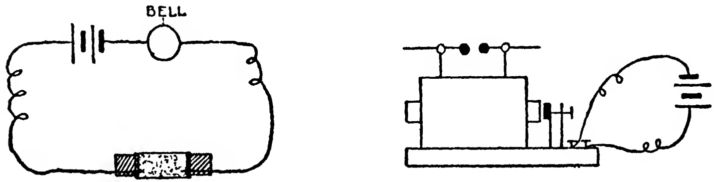


FIG. 43.—A simple coherer.

begin to ring. Tap the tube and repeat the operation. At each spark the bell will ring.

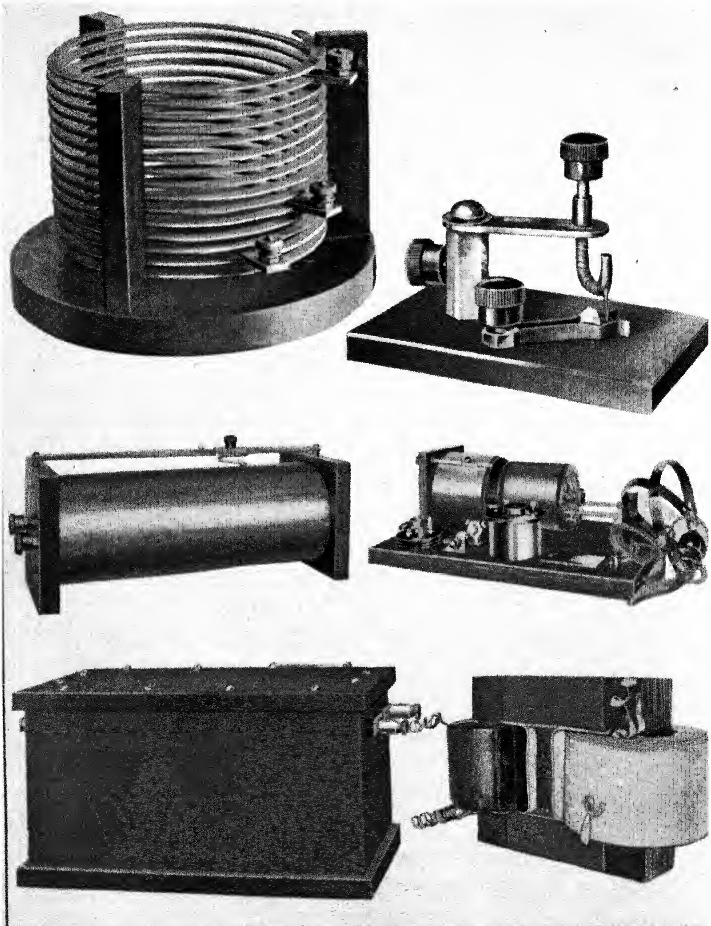
We have here a simple coherer. When the electromagnetic waves from the oscillatory spark discharge fall upon the loose filings in the tube they cohere so as to form a path of low resistance, and permit the flow of current and the ringing of the bell. The tapping of the tube to jar the filings into a state of high resistance performs the function of a decoherer.

Fig. 43 shows the arrangement of the apparatus.

A Simple Wireless Set.—A simple sending and receiving set may be made and put into operation as follows:

THE SENDING SET

The Aerial.—The flat top aerial is one of the easiest to erect and excellent for amateur work. Its height should



By courtesy of Clapp-Eastham Company.

Helix, detector, tuning coil, complete receiving set and transformer, mounted and unmounted.

be from 40 to 60 feet and the ends may be attached to poles fastened to the tops of trees or to the roofs of buildings. If attached to trees, they should extend above the leaves and branches. The length of the aerial should be about twice its height or a little less. Very frequently poles may be fastened to the roofs of two adjacent buildings and the wires stretched between.

Secure two strong wooden bars about two inches in diameter and seven feet long. At six inches from each end and in the middle of each fasten porcelain insulators. Lay the bars on the ground at a distance apart equal to the desired length of the aerial. Cut three lengths of No. 12 copper or aluminum wire and fasten the ends to the insulators. To the middle of each wire solder a long copper wire. These three wires make what is called the "lead-in" and should be joined together just before entering the building. Fasten three short ropes to each bar and tie their ends together. From these ropes lead another over a pulley on the top of the pole and make secure to the building or tree. Each pole should be strengthened with guy ropes.

The lead-in wire should be connected to a single pole double throw switch just before entering the building as shown in Fig. 44 as a lightning protector. When the set is not in use the aerial is connected with the ground, and thus there is no danger of a lightning discharge into the building and apparatus.

Next on the wall just inside the building where the apparatus is to be set up place a two pole double throw switch as shown in Fig. 45, so that the same aerial may be used for both sending and receiving.

A good ground is important and in the country this can frequently be obtained by immersing metal plates in a

cistern or well. In the village or city a heavy copper wire may be attached to a gas or water pipe. This ground wire is independent of the one for the lightning arrester and

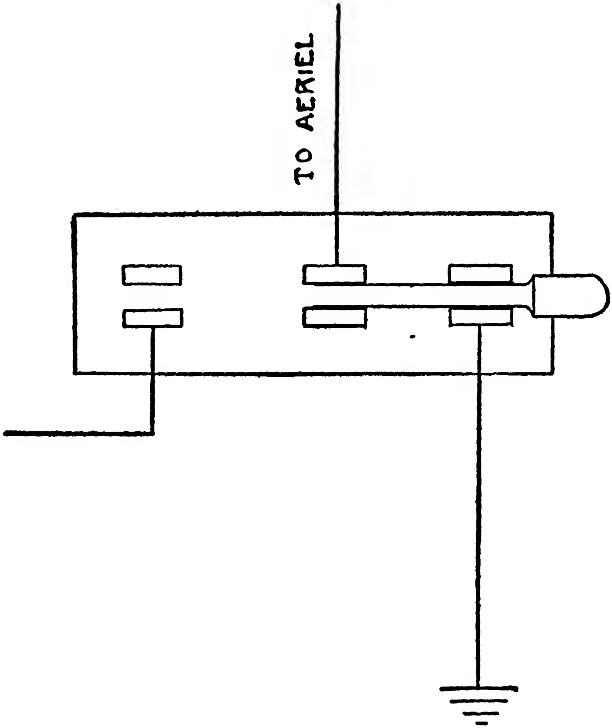


FIG. 44.

by means of the double throw switch may be connected either with the sending or receiving apparatus.

The Spark Coil.—For the production of the spark either batteries and an induction coil may be used or, if alternating current is available, a small wireless transformer

will be simpler to install and operate. If the set is to be used in the country, an induction coil must be employed, and a small one or two-inch coil may be purchased for a few dollars. It will be better to buy this than to attempt

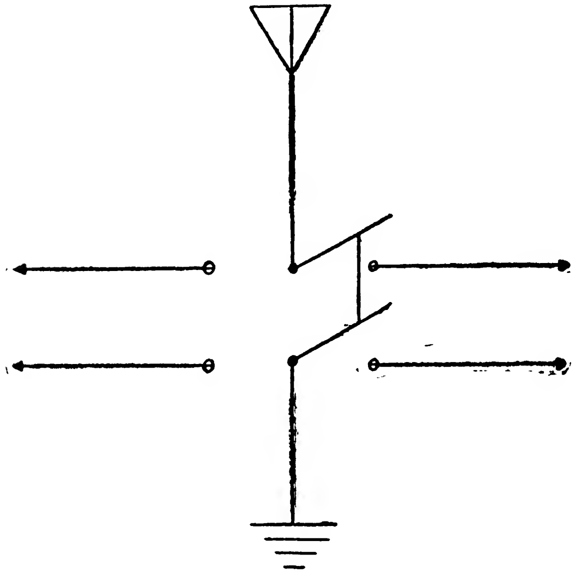


Fig. 45.

to make it. In purchasing a transformer it will be necessary to specify the voltage and number of cycles of the current to be used. This will usually be 110 volts and 60 cycles. Storage batteries or dry cells may be used with an induction coil.

Spark Gap.—A spark gap may be made by screwing two brass binding posts into a board 4 inches square to hold the spark terminals. Then cut two pieces from a 3/8 inch zinc battery rod about 3/4 inch long. Bore and thread

these and fit into them a pair of brass rods $^1/_8$ inch in diameter by 3 inches long. Place a piece of hard rubber on each rod for a handle and mount them in the binding posts as shown in the figure.

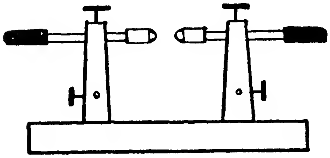


FIG. 46.—Spark gap.

Key.—An inexpensive key to place in the primary circuit of the induction coil or transformer can best be bought.

Condenser.—The condenser for the oscillation circuit can be made as follows: Get 24 thin glass plates 5 by 7 inches or about that. Photographic plates from which the gelatin has been removed will be excellent. Next cut 24 sheets of tinfoil 3 by 5 inches leaving a small projection, or

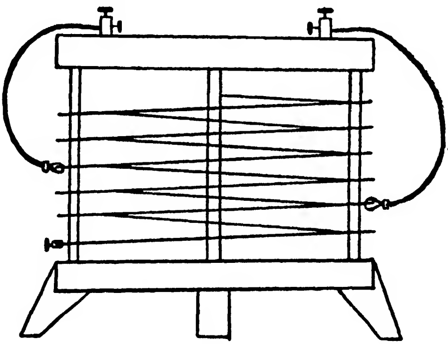


FIG. 47.—Oscillation helix.

"lug," on one corner of each. Place these alternately between the plates of glass so that half of the lugs project on one side and half on the other. Connect the tinfoil lugs on each side to a thin strip of copper foil. Then place the condenser in a wooden box of suitable size and pour full of paraffin leaving the copper strips exposed for connecting in the circuit. Fasten them to binding posts if possible.

Oscillation Helix.—Build a circular frame of wood about 10 inches high and 9 inches in diameter. Cut grooves in the uprights about $^7/_8$ of an inch apart and wind in them $\frac{1}{4}$ inch brass wire. Secure the wire by means of small claw tacks. Insert two binding posts in the wooden top and fasten one to the lower terminal of the wire. Short flexible leads with spring clips should be attached to the two upper posts as shown in Fig. 47.

The Receiving Set

The Detector.—To a base board about 3 by 4 inches fasten an L shaped piece of brass $\frac{3}{4}$ inch wide and $^1/_8$ inch

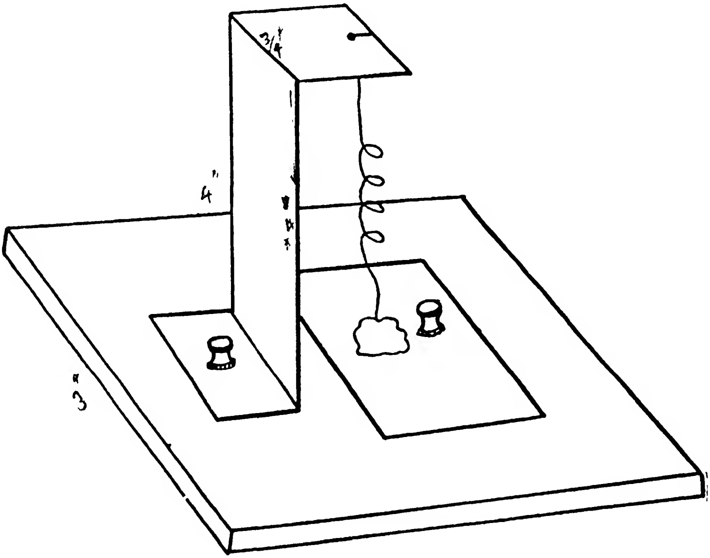


Fig. 48.—Detector.

thick by means of a screw binding post. Make this strip about 4 inches high and directly in under the horizontal

part place a small square of sheet brass. To this horizontal portion attach a fine brass wire and allow it to rest on a small piece of crystal carborundum or galena. Insert another binding post in the sheet brass and the detector will be ready for testing and adjustment.

The Condenser.—This may be made as before but this time use 13 sheets of waxed paper instead of glass 3 by 5 inches and 12 sheets of tinfoil 2 by 4 inches. Provide connections as in the glass plate condenser.

The Tuning Coil.—Procure a hard-wood board 12 inches

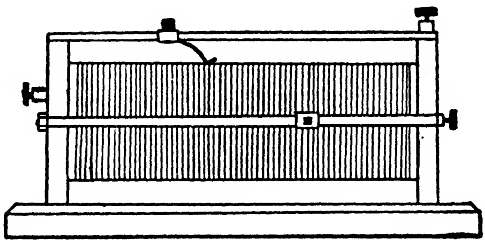


FIG. 49.—Tuning coil.

long, 1 inch thick and 6 inches wide. At each end place a wooden head 4 inches square and between these mount a wooden cylinder 9 inches long and 3 inches in diameter leaving space beneath for pulling the wire. On this cylinder wind as closely as possible without actual contact No. 22 cotton-insulated copper wire and secure one end to a binding post screwed into the wooden head of the coil. This terminal will be connected both to the ground and to the receiving circuit. Across the top and one side of the wooden ends place brass rods carrying brass sliders and terminating in binding posts. The sliders may be made from sheet brass or copper bent to shape and should carry a set-screw and thumb-nut for fastening in position. With

a red-hot iron burn off the insulation in straight lines directly underneath the rods and sliders.

The Receivers.—These must be bought and should be of 1000 ohms resistance.

Both the transmitting and receiving sets may now be assembled on a bench or table in the attic or wherever the

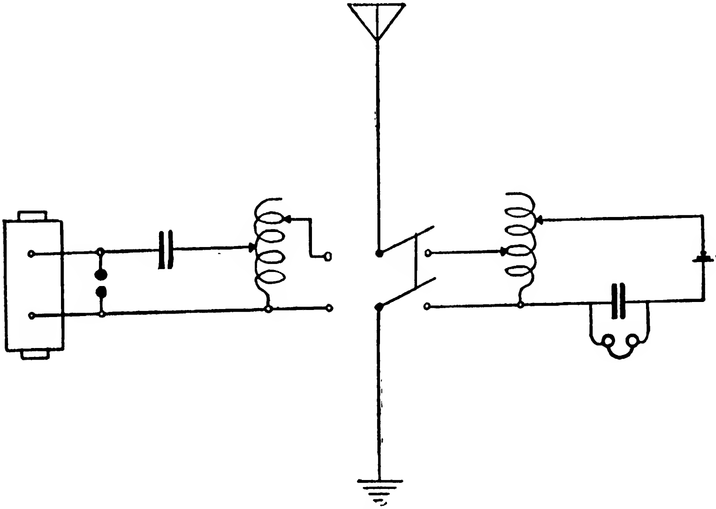


FIG. 50.—Installation of receiving and sending set.

"wireless laboratory" is to be and connected up for operation. A diagram illustrating the proper connection is shown in Fig. 50. The lightning arrester previously described is not shown here. In both the oscillation helix of the transmitting set and the tuning coil of the receiving set close coupling is employed. Such a station will give to a boy the first essentials of amateur training and he may enlarge upon his equipment as his knowledge and experience grow.

CHAPTER VII

TALKING THROUGH THE ETHER

From the time that wireless telegraphy became a fact it was theoretically possible to talk through the ether as well as to send the dots and dashes of the Morse code. But how to construct transmitting apparatus that would project electromagnetic waves capable of reproducing the complex sound vibrations of the human voice was a baffling problem. But baffling problems are not counted as insurmountable obstacles in these days and scientists everywhere began the search for a wireless telephone.

The first approach to the solution of the problem was made by two Englishmen, Simon and Duddell. In 1897, only a year after Marconi's great success with the wireless telegraph, Simon discovered the phenomenon of the speaking arc. This discovery was the basis of the early systems of wireless telephony and is to-day the principle upon which many of them operate. Simon found that if he connected a simple microphone circuit across the terminals of an electric arc and then spoke into the microphone, the alternating currents set up would so affect the arc current as to reproduce the sound. The microphone, which is an ordinary telephone transmitter, may be at a considerable distance from the arc with excellent results. The use of this apparatus became a favorite demonstration with popular lecturers. There was nothing wireless about it but the fact that small alternating currents set up by the

impulses of the human voice could so impose themselves upon another circuit as to reproduce sound vibrations and intelligible speech led to important results.

The simplest form of speaking arc will be understood from the diagram in Fig. 51.

The transmitter is at T, a battery at B, the arc at A and at C and C′ are choke coils which choke back the alter-

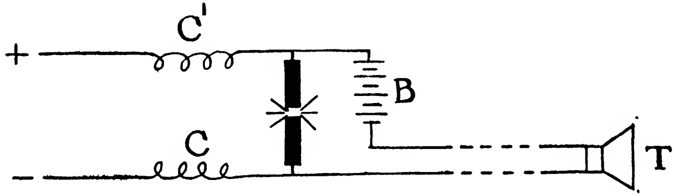


FIG. 51.—The speaking arc.

nating currents from the microphone circuit and confine them to the arc.

Duddell improved the apparatus by placing an ordinary telephone induction coil or wireless transfomer and a condenser in the shunt circuit for the production of the alternating currents.

Now the problem of wireless telephony was to produce at the transmitting station and radiate into space a continuous sustained train of electromagnetic waves upon which could be imposed through the sound waves of the human voice variations capable of being reproduced as sound waves in a distant telephone receiver. In a wireless telegraph transmitter the waves produced by the spark discharge are not continuous, but intermittent and therefore some other means of generating these waves had to be devised. For this purpose Poulsen, a Danish investigator, who bears much the same relation to wireless telephony

that Marconi does to wireless telegraphy, adapted the vibrating arc already mentioned.

How Poulsen made an electric arc generate a sustained oscillating current and maintained a continuous electric oscillation of the aërial will become clear from the

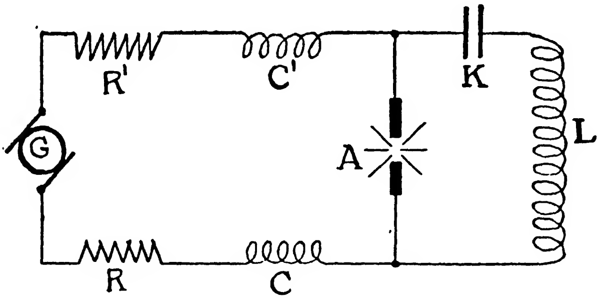


FIG. 52.—Apparatus for producing continuous electric oscillations.

diagram in Fig. 52. A direct current generator sends a current through ordinary electric light carbons producing an arc at A. Resistances to control the current arc placed at R and R′ and choke coils at C and C′. An inductance coil is placed at L and a condenser at K. Now as the current flows through the arc, the condenser K at the same time becomes charged, diminishing the current through the arc but increasing the voltage across it. This serves to charge the condenser still more which, when fully charged, begins to discharge through the arc and inductance coil. But just as the Leyden jar charges itself in the opposite direction so does this condenser and it continues to charge and discharge as long as the current and arc are maintained. Thus it will be seen that a continuous oscillatory current is set up which, if an antenna were provided, would radiate

without interruption sustained trains of undamped electromagnetic waves.

This was just what was needed for wireless telephony and Poulsen's next step was to provide an antenna and microphone transmitter. As shown in Fig. 53, the transmitter was connected to the ground on one side and to the antenna circuit on the other. The action is as follows: The high frequency oscillations of the arc circuit induce corresponding currents in the antenna which gives a continuous radiation of electromagnetic waves. Now as one speaks into the transmitter the vibrations of the voice modify these radiated waves, and when they are received by a distant aërial and pass through the detector circuit, the telephone receiver reproduces the original sound waves. The receiving apparatus is exactly similar to that used in wireless telegraphy.

Shortly after this Poulsen increased the efficiency of transmission by using a water-cooled copper anode and by placing the arc in an atmosphere of hydrogen gas or a hydrocarbon vapor. With this outfit he was able to telephone for distances of several hundred miles and the wireless telephone became a commercial possibility.

Other investigators, notably, Colin and Jeance of France and Dubillier, Collins and DeForest of this country have experimented with the arc telephone. High frequency spark transmitters have also been devised but among the most important inventions are the "Audion Amplifier" and "Oscillion Bulb" of Dr. Lee DeForest. The former was an important factor in the perfection of the transcontinental wire telephone and both have played an important part in the very remarkable recent triumphs of wireless telephony. The Audion Amplifier connected in a wireless receiving set is shown in Fig. 54. It consists of a

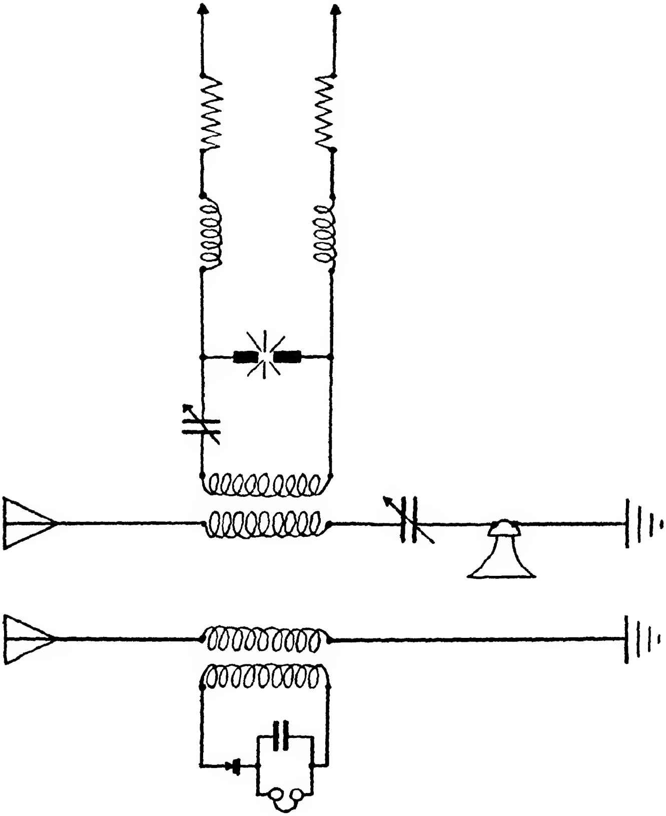


Fig. 53.—Wireless telephone receiving and sending apparatus.

small incandescent lamp bulb exhausted of air, and containing in addition to the usual filament a thin nickel plate, and between this and the filament a nickel wire bent grid-

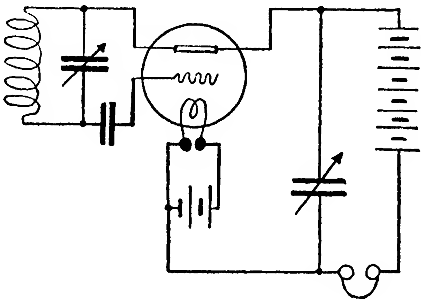


FIG. 54.—The DeForest Audion Amplifier.

shaped. The filament is kept in a state of incandescence by a separate source of electricity. Although the bulb is exhausted it is not a perfect vacuum and the hot, but highly rarified gas left in it acts as a conductor for the battery current from the cold plates to the hot filament. This results in a stream of negatively charged "ions" from the filament to the plate. But any voltage impressed on the nickel grid from the incoming telephonic currents arrests this flow and strange as it may seem a unit charge on the grid has an effect upon the battery and receiver circuit of from six to ten times that value. Therefore, we have the wonderful amplifying power of the bulb. Other vacuum bulbs of a similar nature both for transmitting and receiving have been devised by DeForest and also by Marconi, the General Electric Company, the Western Electric Company and the engineers of the American Telephone and Telegraph Company.

Not satisfied with having established a transcontinental

telephone system, John J. Carty of the American Telephone and Telegraph Company, gathering about him a staff of brilliant American engineers, set out to achieve for America the honor of long distance wireless telephony. With the researches of DeForest and other inventors at their disposal, coupled with true genius in their own ranks, this group of engineers pushed rapidly forward, speaking over constantly increasing distances until on Sept. 29th, 1915, the world witnessed the most remarkable success of radio communication. From his desk at 195 Broadway, New York, Theodore Vail speaking into an ordinary transmitter was connected at Arlington, Virginia, with wireless telephone apparatus attached to the aërials of the U. S. Naval Station. Radiating from there in all directions with the velocity of light, a part of these electromagnetic waves were caught by the antenna of the wireless receiving station at Mare Island, California, and amplified so that John Carty could hear the voice of Mr. Vail and converse with him as easily as though they were in adjoining rooms. And not only this, but on the following day messages sent from the Arlington tower were heard at the wireless receiving station at Pearl Harbor in the Hawaiian Islands, a distance of nearly five thousand miles. Messages were also received at San Diego, California, and at Darien on the Isthmus of Panama. A little later with receiving apparatus installed at the Eiffel Tower, Paris, men talked across the Atlantic.

It is possible now to telephone by wireless from shore-to-ship and ship-to-shore and the time is at hand when a person sitting in his office may be connected at any coast city with wireless apparatus and talk with passengers on transoceanic liners. The practicability of the wireless telephone was demonstrated by the Navy Department

Theodore N. Vail telephoning by wireless from New York to Col. John J. Carty at Mare Island, California.

in May, 1916, when it placed itself in communication with every navy yard in the United States. That the wireless telephone will ever come into serious competition with wire systems is not probable. The cost of installation and operation would be prohibitive and with millions of messages passing simultaneously in all directions the necessary privacy of communication and freedom from interference could not be obtained. As a supplement to wire systems and for oceanic service it undoubtedly has a great field of usefulness. The commercial possibilities of the wireless telephone are as yet almost wholly undeveloped. Great progress is being made in its use, however, by the Army and Navy Departments of the government and at the close of the war we may confidently expect even greater achievements in radio communication than the marvelous triumphs of the past.

In one very important way the development of wireless telephony will differ from that of the wireless telegraph. The latter was and always will be preëminently the province of the amateur. But the cost as yet of building and operating over any considerable distance a reliable radiophone is beyond the reach of most amateurs. As Professor Alfred N. Goldsmith, one of the world's greatest radio experts, says, "the average amateur might just as well not attempt to construct such sets in the present state of the art."

This does not prevent, however, one or two experiments and the construction of a simple wireless telephone that will operate over short distances.

The Talking Arc Light.—If a source of direct current is available so that a carbon arc light can be maintained the apparatus for the talking arc may be arranged as shown in Fig. 55. If possible a hand feed arc lamp should be provided for the carbons, but if this is impossible some other

arrangement can be devised. A resistance at R great enough to cut the voltage across the arc to 50 volts should be provided. For this use the rheostat described under the heating effects of the current in the chapter on electricity.

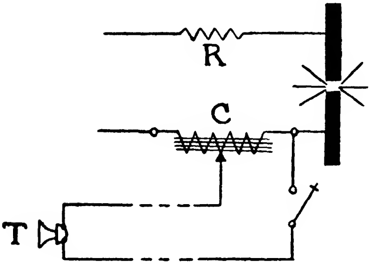


FIG. 55.

At C is a choke coil. The core for this may be made from hay wire cut into pieces about six inches long and bound into a bundle ¾ inch in diameter. Wind this over with three layers of binding tape and upon this insulation wind 7 layers of No. 12 double covered cotton magnet wire. Leave out tapes from the *4th*, *5th* and *6th* layers to permit of adjusting the inductance.

Now across this choke coil shunt an ordinary carbon telephone transmitter with a switch in series. This may be at a considerable distance from the arc if desired. Speak into the transmitter and adjust the amount of inductance in the choke coil by connecting to the different tapes until the sound produced by the arc is loudest and most distinct.

A Simple Wireless Telephone.—Provide an aërial the same as is used in wireless telegraphy and an electric arc as in the previous experiment. The source of current should be alternating and 60 cycles, 110 volts. Choke coils consisting of 60 turns each of No. 10 double covered cotton magnet wire are placed at C and C′. The transformer T may be an ordinary step-up wireless transformer. The carbons should leave only a minute gap at G. The condensers at K and K′ are made like those for wireless telegraphy using in each 4 plates of glass 9 by 11 inches with

tinfoils between. The oscillation transformer T′ may be the same as that used in any simple wireless set. At M place an ordinary carbon transmitter.

Now tune the current until oscillations are set up which can be determined by placing a small glow lamp across the

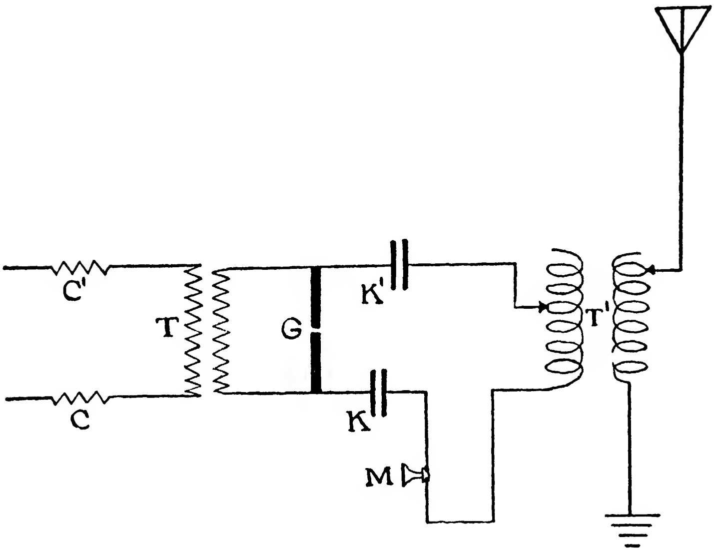


FIG. 56.

secondary of the aërial transformer. This will light when the proper amount of current is flowing through the primary of the step-up transformer. During this adjustment disconnect the aërial and ground.

The receiving set may be the same as that used in wireless telegraphy and the two sets must be tuned into resonance with each other. Over short distances such a wireless telephone will give very satisfactory results.

Chapter VIII

THE STORY OF AVIATION

As I began to write this chapter on the achievements of aviation the very loud hum of motors and an unusual commotion outside called me to the street and looking up I saw, but a short distance above, the largest dirigible it has ever been my pleasure to observe. Like a huge bird conscious of its power and majestic in its movements this man-made craft rose and fell, turned whither it would or hovered over a single spot with all the grace and ease of its feathered superiors in the art of aërial navigation. And as I watched, there came fluttering down, what at first glance looked like a flock of white winged doves, but as one of the missives dropped at my feet I picked it up and on it read this inscription:

"This copy of the 'Star Spangled Banner' was dropped by United States aviators flying over more than 100,000 foreign-born citizens as they paraded on Fifth Avenue, New York City, in a great public pledge of loyalty to the nation, July 4, 1918. Every race and every nationality was represented. Regiments of American sailors, American soldiers and United States marines led the marchers while the nation's progress in the war was pictured on great floats."

Followed by aëroplanes this aërial demonstration is a fitting symbol of that supremacy in the air which more than anything else may be a decisive factor in the tremen-

dous struggle for human freedom and the future of civilization. When we recall that less than two decades ago real mastery of the air was apparently an iridescent dream, the actualities of the present remind us once more that the "impossible" is forever giving way before the inventive genius of the race. Under the spur of military necessity the science of aviation has ceased to be a sport and become in an incredibly short space of time one of the most formidable weapons in the grim business of war. The but recently established mail routes are only a forecast of the tremendous commercial possibilities of the future. Even now trans-atlantic aëroplane service seems entirely practicable and tomorrow it will be a fact. Out of this holocaust of war the world is surely moving forward and inventions are being perfected which will be of the utmost importance to industrial development when the nations of the earth "shall beat their swords into plow-shares" and return once more to the pursuits of peace.

To conquer the atmosphere and to be able to glide through it at will with the ease and perfection of the birds of the air has always had a wonderful fascination for the imagination of the race. The one essential element lacking in man's physical equipment has seemed to be wings. The angels in heaven are pictured as possessing the power of flight and from the Middle Ages come fanciful tales of sorcerers and magicians who likewise were endowed with this supernatural gift. But until very recently flying has been regarded as the most fitting symbol for the utterly impossible. When we have wished to express our complete disbelief in the success of any project we have said, "it is as impossible as flying." But in every century there have been rare spirits who persisted in dreaming of the possibility of mechanical flight and once more these dream-

ers have had their way. The visions of the past are the realities of the present and one more step has been taken toward the annihilation of space and time.

That human beings should ever be able to devise means of lifting themselves into the great ocean of air at whose bottom they live seemed too absurd for serious consideration. Seemingly weightless it was known that the atmosphere possessed 15 pounds pressure per square inch and although apparently non-resistant it could drive ships over the sea and do the utmost violence to trees and buildings in the fury of a storm. That a given volume of air actually had a definite weight was known to such scientists as Cavendish, Black and Priestly. Cavendish, too, in 1766 had done important work on hydrogen gas, which he called inflammable air, and had shown that it weighed about one-fourteenth as much as an equal bulk of real air. An Italian, Tiberius Cavallo, had made toy-ballons inflated with hydrogen. But the honor of first making an actual balloon of considerable size and lifting power belongs to the Montgolfier brothers of Annonay, France. Knowing nothing of hydrogen gas, these experimenters made use of hot air and inflated their gas bag by building a fire underneath and filling it with the hot products of combustion. After succeeding with several small balloons they made a large gas bag from linen and paper having a diameter of 35 feet and a capacity of 23,000 cubic feet. This rose to a height of 1000 feet and traveled a distance of a mile. On June 5, 1783, the Montgolfiers gave a public demonstration before a large audience of thoroughly skeptical observers. When, however, the balloon carrying a weight of 300 pounds in its bag and frame shot into the air and rising to a height of 6000 feet traveled a mile and a half with the wind, excitement and enthusiasm knew no bounds. Paris went

balloon mad and by public subscription raised money to defray the cost of further experiments.

Shortly after this a Frenchman named Charles filled a balloon of 22,000 cubic feet capacity with hydrogen using 498 pounds of sulphuric acid and 1000 pounds of iron filings to generate the gas. The ascension was made on August 27th of 1783. In a few seconds the balloon rose to a height of over 3000 feet and then disappeared in the clouds. Three-quarters of an hour later it fell in a distant field much to the amazement and terror of the natives who attacked it as a new monster of flight, and tying the bag and frame to a horse's tail sent the horse galloping across the country.

Rozier, another Frenchman, was the first man to ascend in a balloon and in the first two years of aërial navigation at least fifty persons made more or less extended voyages. In attempting to cross the Channel to England, the brave Rozier lost his life. The balloon was driven back toward the land and, the gas bag taking fire, he was dashed to the ground. In the French Revolution balloons were first used for military purposes. Napoleon took several with him on his expedition to Egypt and in the battle of Fleurus General Jourdain was furnished valuable information of the Austrian positions by balloon scouts. In 1797, Garnerin invented the parachute, and in 1823, George Green of England utilized coal gas instead of hydrogen for the inflation of the balloon, which, though not having so great a lifting power, was much cheaper. Ballooning became a popular sport. Later in the Crimean War, in the Civil War and in the Franco-Prussian War of 1871, the balloon demonstrated its military importance. When Paris was besieged in 1871 its only means of communication with the outside world was by balloons. During the siege the

inhabitants of the beleagured city sent out 64 balloons carrying 155 persons and more than 3,000,000 letters.

In the Great War of today captive, or kite-balloons, anchored by a rope to the ground are of immense importance. The elongated gas bag of such a balloon is four-fifths filled with hydrogen and the remaining one-fifth of the space is occupied by a small bag called the ballonnet, which is filled with air. This is automatically inflated by pumping air from the outside and maintains a constant pressure within the gas bag. When, through changes of altitude or temperature, the inside pressure exceeds a certain value, a valve opens and allows air to escape from the ballonnet until the pressure has been reduced to the proper amount. As the reverse pressure change occurs air is automatically pumped into the ballonnet.

On the Western front hundreds of these captive balloons dot the rears of the Allied and German positions. In the basket slung beneath the gas bag officers with field glasses and telescopes observe the enemy positions and direct the artillery fire of their own guns. These men are provided with parachutes to insure a safe escape in case of attack. Such balloons are superior to aeroplanes for this work because of their ability to hover over a single spot. Just preceeding the great battle of the Somme in 1916, the Allies sent fighting aëroplanes to attack the German observation balloons and drive them from the air before beginning the big drive.

The Dirigible.—The typical balloon, however, simply drifts with the wind and is at the mercy of every gust that blows. While a great achievement and of much practical importance, nevertheless the balloon did not satisfy, but only stimulated, man's intense longing really to navigate the air. The aëronaut's supreme ambition was to direct his

own course and to imitate so far as possible the movements of the birds. Although numerous experimenters had for at least three centuries endeavored to perfect birdlike mechanisms capable of actual flight, after the advent of the balloon, the surest means of success seemed to lie in some sort of dirigible balloon. But it took a century to work out the requirements for complete success. The *ballonnet*, *the stabilizing fins*, the *horizontal rudder* and the *gasoline engine* were prime essentials, and at last they came.

The first real successful attempt at the construction of a dirigible balloon was made by Henri Giffard of Paris in 1852. He adopted the familiar cigar-shaped gas bag so common in later construction and beneath it suspended a steam engine that drove a screw propeller. The envelope contained 90,000 cubic feet of coal gas, being 150 feet long and 40 feet in diameter. With this dirigible he was able to make 7 miles an hour against a strong wind and by means of a rudder succeeded in steering it in any desired direction. Although a great success, Giffard abandoned aëronautics and nothing further was done for more than a quarter of a century.

Numerous other attempts were made during the last quarter of the nineteenth century but not until the advent of the young Brazilian, Santos-Dumont, in 1898 was any real progress made. He had come to Paris with great wealth and an immense fund of enthusiasm to devote his genius and intense energy to the science of aëronautics. Just at this time, too, came the automobile with the wonderful development of the gasoline engine. The elements of success were now at hand and no greater enthusiast has ever appeared than Santos-Dumont. In rapid succession he built six light fragile dirigibles, each driven by a gasoline motor and with the last he won the prize of 100,000 francs

offered by M. Deutsch to the aëronaut who should successfully round the Eiffel Tower and return to the specified starting point in half an hour. On October 29th, 1900, Santos-Dumont accomplished the feat in 29 minutes and 30 seconds to the admiration of the gaping thousands who watched the flight with the keenest interest.

In the meantime Count Zeppelin of Germany had been working on his now famous leviathans of the air. These immense airships bore about the same relation to the "cockle-shell" dirigibles of Santos-Dumont that an ocean liner bears to a tug boat. The Zeppelin, although the same in principle as Giffard's dirigible, represents several radical departures and in point of efficiency the two are as far apart as the stage coach and the modern express train. Instead of maintaining the shape of the hull by a gas pressure inside the envelop superior to the atmospheric pressure outside, the Zeppelin makes use of a rigid framework covered with fabric which encloses a comparatively large number of drum-shaped gas bags. These gas bags are filled with hydrogen and because of the immense size of the craft their lifting power is very great. If one or even several of these compartments are destroyed the lifting power and ability to continue the journey are only partly impaired. The gasoline engine, without which successful air navigation would be utterly impossible, is of course used. The first Zeppelin built was 30 feet in diameter, 400 feet long and had 17 gas compartments. The company that built it was capitalized at $200,000 and the cost of the shed for housing it was $50,000. The latest Zeppelins are 650 feet long and are driven by six 250 horsepower motors.

The Zeppelin, like the balloon, floats in the air because the weight of air displaced by it is equal to the weight of the Zeppelin and contents. If it rises it is because the weight

of air displaced exceeds that of the Zeppelin and just as a stick thrust beneath the water will rise, so will the Zeppelin. The balloon or Zeppelin will continue to rise until its *average* density, or weight per cubic foot, is equal to that of the surrounding air. If the balloon is to rise, ballast, either sand or water, is thrown overboard. This lowers the average density and the balloon shoots upward. When the balloon is to descend gas is allowed to escape by opening a valve in the gas bag. In the case of the Zeppelin there are air bags in the compartments as well as hydrogen drums. The two are in direct contact so that the pressure of one reacts directly on that of the other. Now if the Zeppelin is to rise hydrogen is pumped from steel containers into the hydrogen drums and at the same time air is forced out of the air bags. Since hydrogen is fourteen times lighter than air this increases the buoyancy and the Zeppelin rises. When the Zeppelin is to descend hydrogen is pumped back into the steel compression tanks and air at the same time is forced into the air bags. These changes can be effected very quickly and rapid movements thereby executed. In addition the Zeppelin carries elevating rudders like an aëroplane and can use them for quick movements, but to remain permanently at a higher or lower level the density of the airship must be made equal to that of the air outside. Although a Zeppelin weighs 20 tons, its size is so great and hydrogen so light that it navigates the air with perfect ease. A Zeppelin starts at an altitute of 5000 feet, but by the time it has traveled from Berlin to London say, its consumption of fuel has so decreased its weight that it has risen several thousand feet higher. One very disconcerting feature to gunners operating anti-Zeppelin guns is the fact that after the dropping of each bomb the Zeppelin, lightened by the loss of ballast, immediately rises about 200 feet. The max-

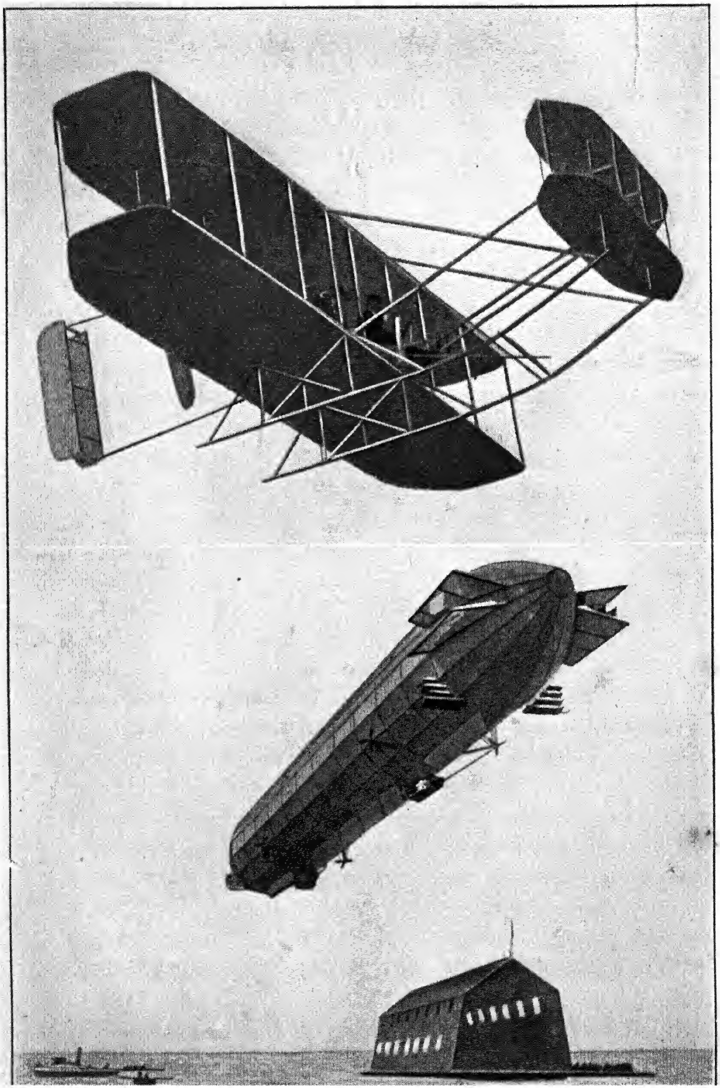
imum altitude for Zeppelin navigation is said to be 10,000 feet. Balloons, however, have risen to altitudes of seven miles.

The flight of the first Zeppelin was a failure, but the Zeppelin II, the fifth creation of Count Zeppelin, on May 29th, 1909, made a successful voyage of 850 miles. Before the war large *air-liners* carrying 24 persons and fitted with a luxurious cabin and restaurant were engaged in passenger service.

At the same time, the German government created the *air-cruiser* for military purposes. In 1912, the first of these huge naval air-craft on a trial trip covered a distance of 1,200 miles carrying a crew of 31 and a wireless outfit having a range of 200 miles. At the beginning of the war Germany had a fleet of a dozen of these high speed, long range Zeppelin cruisers. To offset them the Allies had only a few pressure air ships lacking both in speed and range. But in a short time the development of the bombing aëroplane and the anti-aircraft gun had destroyed the usefulness of the Zeppelin for scouting purposes and confined its operations to the nighttime.

The earlier type of dirigible pressure air-ship has proved very useful in anti-submarine defense, mine sweeping and some minor scouting operations. When the war is over, however, this type will undoubtedly give way to the rigid Zeppelin, which seems capable of great commercial development and to be especially well adapted to transatlantic service.

The Aëroplane.—But the dirigible did not really conquer the fields of air. The ardor, the peril and the joy of the aviator had not been experienced. To fly like the birds with a heavier-than-air machine and to rise to a complete mastery of the elements of space was the real aspiration



An early Wright biplane; and a Zeppelin flying over Lake Constance.

of every true aëronaut. The close of the last century and the first decade of the present witnessed very remarkable advances in this direction, but four years of war have brought results beyond the dreams of the most ardent enthusiasts. Truly the heroes of the air have come into their own and like the Vikings of the sea their daring exploits will be told in song and story through the centuries to come.

There was the example of the birds, weighing a thousand times more than the air displaced by them and yet flying with perfect ease. The flight of large birds, soaring and gliding with outstretched wings for hours without the quiver of a muscle, so far as could be observed, was and still is very largely a mystery. But if birds could fly why not men? And numerous were the attempts to accomplish this difficult feat. Helmholtz "demonstrated" that man does not possess the muscular strength to propel himself through the air by the flapping of artificial wings and so far no one has succeeded in doing this, though it would be unwise to predict that it never can be done.

That there is a vast difference in the lifting power of still air and air in motion is a matter of common experience. Any mass of matter, no matter how light, when in motion possesses energy and the ability to do work. One of the commonest examples of this is the ordinary kite. In the presence of a stiff breeze a boy may stand in his tracks and as he pays out string his kite, though many times heavier than air, mounts skyward. If there is no wind he well knows that he can make one by running forward with the kite-string and that just as before the kite will rise.

More than a century ago, Sir George Cayley, an Englishman, worked out the principles upon which the modern

aëroplane operates. In 1846, Stringfellow, another Englishman, constructed a model aëroplane run by a steam engine which made several successful flights. In 1866, Wenham, also of England, developed the multiple surface aëroplane and Stringfellow embodied the principle in a successful triplane. In 1894, Sir Hiram Maxim built a heavier-than-air machine weighing about 4 tons and driven by screw-propellers operated by a 360 horsepower steam engine. In a trial flight this huge machine actually succeeded in leaving the ground and going a distance of 300 feet. It demonstrated the possibility of mechanical flight but little more.

About this time Professor S. P. Langley, Secretary of the Smithsonian Institution, built a wonderfully successful little model. The width of the wings was 12 feet, the length of the machine 16 feet and it was driven by a steam engine which developed one and one-half horsepower and weighed only 26 ounces. The total weight of the machine was 31 pounds. When given a trial, this model aëroplane rose in the face of a strong wind to a height of 100 feet and traveled a distance of three-quarters of a mile, coming to rest only when its steam was exhausted and then gliding gracefully to the earth. In 1903, Professor Langley built a steam driven man-lifting machine, but a defective launching device resulted in plunging it into the Potomac river. Professor Langley gave up the task but following his death shortly after this, his machine was unearthed and made to fly.

In the meantime Otto Lilienthal in Europe and O. Chanute in this country had been making extensive experiments with gliders. A glider is simply an aëroplane without motive power and Lilienthal constructed numerous gliders having correctly curved surfaces made of linen stretched

over light wooden frames. His first machine had a total area of about 14 square yards and weighed 40 pounds. In the center was an opening for the operator to stand holding the machine in his hands. Lilienthal had given close study to the movements of the birds and he had observed that a soaring bird having once alighted could not raise himself into the air without making an initial run to acquire the necessary speed. Adopting this method he began his practice flights by running down a gently sloping hill against the wind. When he had gained the necessary momentum he would let himself go with the result that he could glide slowly and easily toward the foot of the hill. The front of the plane was inclined upward a few degrees to catch the wind and the pressure of the air as it slid beneath the canvas surface gave supporting power to the machine. The initial run and the weight of the operator take the place of the string in the kite and the motor in the aëroplane.

Lilienthal, learning by experience, constantly improved his machine, acquiring great skill in maintaining his equilibrium and in one flight succeeded in gliding a distance of 1,200 feet. At times he could rise above his starting point and when wind conditions were favorable he could sail from a hilltop without the initial run. Unfortunately he met his death by a fall from his glider in 1896, but the carefully preserved record of his work was of great assistance to his successors and he must always be remembered as a pioneer of aviation.

But the news of the death of Lilienthal stimulated two unknown brothers in an Ohio town to study and investigate the possibilities of mechanical flight. All the world has long since come to know Wilbur and Orville Wright of Dayton, Ohio, as the inventors of the first man-carrying, motor-

driven aëroplane. Their interest in aëronautics began when as lads their father brought home to them one night a small helicoptere flying machine. Later they read of the work of Lilienthal and Chanute and began making experiments with gliders of their own construction. Like every great invention success came only after years of patient research and persistent effort. History scarcely records a great achievement won at a larger cost of painstaking and exhaustive experimentation. They were compelled to develop for themselves the fundamental principles of aëronautics, and the unreliable data upon which all flying machines had previously been based caused them much unnecessary work. During this period, however, they were not forced to work in poverty, for a successful bicycle repair business kept them supplied with funds. Their plan was to read and experiment during all their available spare time and then each autumn to spend several weeks on the bleak, windswept sand dunes at Kitty Hawk, North Carolina, in actual gliding and flying. Increasing success marked the progress of their work, and by the autumn of 1903 they had mastered the elementary principles of flight and given to the aëroplane the one missing link essential to self-controlled equilibrium. This was the warping mechanism to prevent sidewise tipping and to keep the machine on an even keel. With such a machine they acquired greater skill than had ever before been exhibited in gliding experiments.

The one thing now lacking for real sustained flying was a light reliable motor and this they proceeded to build. Being practical mechanics they built a gasoline motor of 12 horsepower with a fuel capacity of a few minutes' duration and giving a speed of 30 miles per hour and installed it in their glider. Then on December 17th, 1903, in the bitter

cold and raw winds of the Kitty Hawk sand dunes their first biplane carrying one of the brothers made a successful flight. For the first time in history a self-propelled flying machine lifted itself from the ground with its own power and under the guidance of its pilot made a free flight and landed in safety. Four flights were made at that time, the last one having a duration of 59 seconds and covering 850 feet. During these flights, too, they were not at the mercy of the wind but were able to steer their machine up or down or to the right or left as they chose. The flight by Sir Hiram Maxim had been an uncontrolled flight and ended with the first attempt.

Only two years before, the great astronomer, Simon Newcomb, had stated that the construction of air craft that would carry even a single man "requires the discovery of some new metal or some new force." But now the "impossible" had once more been attained and as Wilbur Wright said, "the age of the flying machine had come at last." And yet the world knew practically nothing of the great achievement. One of the chief characteristics of these two men was modesty. Their experiments had not been carried on in secret but they had not been advertised. Very quietly they returned home and in 1904 and in 1905 continued their flights at Dayton with two new machines. During this time 160 flights were made and the distances covered totalled as many miles. The last flight of 1905 covered 24 miles and lasted 38 minutes. In this practice work the Wrights were patiently working out details and putting their machine under better control. The whole world will forever stand debtor to them for this groundwork without which the marvelous present day success of aviation would be utterly impossible.

The first Wright aëroplane obtained its lifting power

from two horizontally placed parallel planes of canvas stretched over light wood frames and placed crosswise of the machine. In front were two horizontal parallel rudders for raising and lowering the machine in flight, and at the back two vertical rudders for sidewise steering. Two wooden propellers similar to ship-propellers were placed just back of the two main planes. The machine was kept on an even keel by the device for warping the ends of the planes and thereby changing the angle at which the air strikes them. This device is probably the most distinct contribution to the aëroplane mechanism made by the Wright brothers. In 1906, they obtained a patent on their machine and sought to introduce it to the world.

The success of the aëroplane now became rapid and certain. The invention of a light powerful gasoline engine was a prime factor and the Wright warping device insured lateral control, which had hitherto been impossible. Experimenters were at work abroad, too, particularly in France. In 1908 Henry Farman, an Englishman living in Paris, aroused the enthusiasm of the French people and won a 2,000-franc prize by flying over a prescribed circular course, a distance of 1,600 yards, and returning to the starting place. The Wrights had more than four years before made more remarkable flights, but the world still remained in ignorance of them. In the autumn of 1908, however, Orville Wright in America and Wilbur Wright in France began a series of public demonstrations that electrified the world and forever settled the question as to whom belonged credit for having conquered the air. On September 12th Orville Wright at Fort Meyer, Virginia, flew continuously about a circular course for an hour and fifteen minutes. Nothing like it had ever before been witnessed and the whole world from that moment knew that mechanical

flight was not only a possibility but a magnificent success. This great triumph was marred, however, by an accident a few days later which wrecked the machine and resulted in the death of Lieutenant Selfridge, a companion in flight of the inventor. This is the first death chargeable to aviation in a self-propelled, heavier-than-air machine.

At the same time in France Wilbur Wright was convincing the skeptical citizens of that country of his just claims to having conquered the air. He made numerous flights to the delight of the emotional and enthusiastic French public, in one of which he remained in the air for two hours, twenty minutes and twenty-three seconds.

On July 19, 1909, Hubert Latham attempted to cross the Channel to England but when he had nearly attained his goal his motor failed and he plunged into the water, being rescued, however, without injury. Six days later on July 25th, Louis Bleriot flying in a small monoplane succeeded in making the passage. In this same month Orville Wright met the endurance test of the United States Government by flying for more than an hour with a passenger in the machine. Later in this year he made a number of flights in Berlin demonstrating the superiority of the aëroplane to the unwieldy Zeppelin. In October of 1909 at the Hudson-Fulton Centenary Celebration Wilbur Wright made a spectacular flight from Governor's Island over the warships anchored in the North river up the Hudson and back to the starting point.

The Wright brothers now received the honor which was their due. They were decorated by the crowned heads of Europe and awarded medals by many scientific societies, aëro clubs and universities, by the Smithsonian Institution, the City of Dayton, the State of Ohio and by Congress.

Another aëroplane inventor who has done much notable

work and of whom all Americans are justly proud is Glenn H. Curtiss. A young bicycle mechanic, he early began the study of aëronautics and in August of 1909 with a biplane and 8-cylinder engine of his own construction won the chief speed contest in the International Aviation meet at Rheims. In the following spring he further distinguished himself by making a flight from Albany to New York, covering a distance of $142^1/_2$ miles in 2 hours and 54 minutes, at an average speed of 50 miles an hour and with only one stop. Since then he has made many notable flights and has done very important work in the development of aëroplane construction, his most important contribution being the "flying boat," a sea-plane for use in naval warfare. The Curtiss Engineering Corporation of Buffalo is one of the largest aëroplane plants in the country.

To complete the aëroplane romance and tell the story of the remarkable development between 1909 and the outbreak of the great war would require a volume in itself. During this period the chief object of aviation was sport. The commercial and military usefulness of the aëroplane were seen, but little real development in these directions was made. And yet the progress made in these years was fundamental to the great success of military aviation in the years immediately following. The mastery of mechanical details and preëminently the improvement of the gasoline engine were vital factors. To the Voisin and Farman brothers the world owes the development of the pusher biplane and to Louis Brêgnet and A. V. Roe the tractor biplane. The Seguin brothers of France invented the famous Gnome engine which has done more for the progress of aviation than any other one invention. Aëroplane engines weighing but little more than two pounds per horsepower are in common use. The power of these engines is

much higher than that used in the early machines, giving much greater speeds and making possible the use of smaller planes. Several modern engines are shown in accompanying cuts.

Military Aviation.—At the outbreak of the Great War the possibilities of the aëroplane in military operations were but little known. Its chief use up to this time had been for scouting purposes and it is now perfectly evident that none of the belligerents had any adequate conception of the tremendous part that aviation would play in the winning of the great conflict. But from the very start the aëroplane has demonstrated its immense usefulness At the battle of Mons an aviator saved the British expeditionary force from annihilation by reporting that the Germans had much larger numbers than had been anticipated. It was another aviator at the decisive battle of the Marne who made known the gap between Von Bulow's and Von Hansen's armies and enabled General Foch to compel a German retreat by driving a wedge into their lines. These and many other instances firmly established the great value of aërial scouting and each side began to study the art of aviation as never before and prepared to make vast additions to its aëroplane fleets.

Perfection in aëroplane construction came with a rapidity never before equaled in any great invention. It was almost meteoric. The views of scientists and strategists were crystallized and put to test. The essential mechanism, however, of the early Wright models remained. No radical departure was made, but just as the steam engine of the forties evolved into the powerful high speed locomotive of the twentieth century, so did the aëroplane almost over night change into a powerful fighting machine. Strong unbreakable wings, a boat body enclosing crew, engines,

steering gear and tanks, together with engines of more than 200 horsepower and developing speeds of 120 miles an hour, came in rapid succession. With increased power and speed any weather can be braved and the size of the wings to give the same lifting power can be decreased many times. The factor of safety has increased to nearly 100 per cent. Engine troubles are almost obsolete. Military officers fly freely over the Alps without any possibility of landing, and there is not the slightest doubt that by the spring of 1919 transatlantic service will be an accomplished fact.

The *scouting aëroplane* is a two seater of great speed range whose duty it is to observe enemy positions and movements and to report them immediately to headquarters. Its armament consists of a single defensive gun and its crew is composed of a pilot and trained observer. The height at which scouting planes fly must be above 6,000 feet in order to escape bullets from anti-air craft guns. At this altitude the observer must be able to distinguish a convoy train from artillery, howitzers from field guns, or a supply depot from a harmless landmark. He must also be able to operate an aëroplane camera and to manipulate a wireless outfit. The whole attention of the pilot is absorbed in steering such a zigzag course as to escape the fire of enemy aircraft. Even though riddled with bullets if the petrol tank and machinery remain intact these scouting planes will make a safe return. Besides making the usual observations these planes supply to the artillery the exact range of enemy objectives to be shelled. At headquarters the photographs are quickly made into lantern slides and thrown upon a screen by a stereopticon which brings out and greatly magnifies every detail.

Very soon it became apparent that scouting planes must be afforded protection. It also became necessary to de-

stroy kite-balloons and to drive off the scouting planes of the enemy. And for this purpose there was invented the high speed, single-seated tractor which can out-fly and out-manœuvre any other type of machine. It will fly 130 miles per hour and climb 1,000 feet per minute. The pilot operates a machine gun fixed rigidly in front of him and aims it by steering the aëroplane directly against the target. This necessitates shooting straight through the propeller blades, but a timing device connected with the gun makes it possible to fire bullets at the rate of 400 per minute without hitting the blades. This invention vital to the success of the fighting plane was made by the famous French airman, Ronald Garros. These fighting planes also convoy bombing machines and frequently go in large numbers. When a fighting flotilla from either side seeks to secure mastery of the air the only way to combat the machines is by attacking them with other machines. And then ensues a battle royal, above the clouds it may be, where with dizzy manœuvres and lightning like rapidity of movement the exploits of Paul Jones, Lord Nelson and Admiral Farragut are put into the shade.

The *bombing planes* are the dreadnaughts of the air. The new Handley-Page plane described by Mr. John D. Ryan, head of the Aircraft Production Board, as "one of the most powerful ever built" is equipped with two of the famous Liberty motors developing over 800 horsepower and will carry from a ton and a half to two tons of explosives. In fleets of sometimes 50 and 60 machines convoyed by high speed fighting planes these dreadnaughts make raids far over enemy lines dropping tons of explosives on airship sheds, supply depots, railway junctions, munition plants, submarine bases and coast defenses. Most severe punishment both moral and material is inflicted in this

way, and it is safe to say that could either belligerent increase the number of its bombing planes to 15,000, without adequate means of defense on the part of the enemy, a complete victory would be won in less than three months. Such a fleet could drop 50,000 tons of high explosives upon the enemy every 24 hours and neither the physical endurance nor the morale of any nation could long withstand such terrific bombardment. If history ever records another surprise attack like the fell swoop of Germany in 1914, it will come through the air and woe be to the defenseless nation against whom the attack is directed.

But for the promotion of domestic and foreign trade, social and political intercourse among nations and the breaking down of the barriers of time and space, this great conflict has forged an instrument more potent than any other invention in modern times. Even now no less an authority than Claude Graham-White freely predicts speeds of from 250 to 300 miles an hour. The international financier or statesman may transact business in New York and Washington one day and in London and Paris the next. Transcontinental aërial mail and express routes will separate New York and San Francisco by only twenty hours. Through passenger service, too, with every provision for comfort and safety will make the transit of the continent in even less time. The time and money thus saved in a single year will mount into colossal figures. This old earth suffering in rapid succession the offensives of the steam engine, the telegraph, the telephone, the electric motor, the wireless telegraph and now the aëroplane, the modern meteor of the skies, is rapidly dwindling into truly insignificant proportions. And just in proportion as men and nations are brought into more intimate relations the forces that make for peace and the prohibition of war multiply

and strengthen. Surely in this great service of the future the aviator will take high rank.

How prophetic of present and future achievement were the words of Tennyson:

"For I dipt into the future, far as human eye could see,
Saw the Vision of the world, and all the wonder that would be;
Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales;
Heard the heavens fill with shouting, and there rain'd a ghastly dew
From the nation's airy navies grappling in the central blue;
Far along the world-wide whisper of the south-wind rushing warm,
With the standards of the peoples plunging through the thunder-storm;
Till the war-drum throbb'd no longer, and the battle-flags were furl'd
In the Parliament of man, the Federation of the World."

CHAPTER IX

THE PRINCIPLES OF THE AËROPLANE

How does it happen that a machine many times heavier than the air through which it moves does not fall? What sustains it? In a vague way we know that the air pressure does it. But how does there happen to be air pressure sufficient for such a gigantic task? To most people this whole subject is shrouded in more or less of mystery. And yet the explanation is not difficult to understand.

The Kite.—We will start with a kite, which if flying in still air with a boy and string for motor is a miniature tractor monoplane. When the air is still any boy knows that he must run like the wind if he is to succeed in lifting his kite off the ground. But presently as he increases his speed the breeze which he creates by his own running catches beneath the inclined surface of the kite and it begins to rise. Now a kite is a heavier-than-air machine, and if it rises it must be that some force has been developed sufficient not only to support the weight of the machine but also to lift it against the force of gravity as well. And this force has come about by pulling the kite plane rapidly through the air with its front edge raised a little so that the "wind" will catch it. Evidently this artificial breeze has produced a pressure on the kite which in part at least has been upward and able to lift it.

Now the most common property of all matter including the air is inertia. Inertia means inactivity. A body at rest tends to remain at rest or if in motion to continue in

motion. And to every action there is an equal and opposite reaction. These are familiar laws of physics. If you hang a heavy weight from a hook in the ceiling, the hook pulls back with an equal and opposite force and if it did not the weight would fall. Strike the surface of a body of water a quick sharp blow with a long thin board and the water does not yield but acts like a solid. When you take a running jump the earth reacts against your feet and if it did not you could not leave the ground. When caught in a violent wind storm your body reacts against the rushing air and if the wind pressure proves too great you are driven before it like a kite rising in a brisk gale. Could your body be supplied with a trailing appendage like the tail of a kite so as to insure stability you might easily be lifted skyward kite fashion. A column of natural gas issuing from a newly driven gas well frequently gushes forth with such high velocity and tremendous energy as to make it behave like a rigid solid. Give velocity to air and it possesses energy.

Air at rest possesses inertia and when we strike it a sharp blow or pull a kite through it the tendency is to remain at rest and the air reacts exerting pressure on the surface. The amount of this pressure will depend upon the force of the blow or the speed of the kite. If we double the speed of the kite we will multiply the air pressure upon its surface by four, and if we treble it the pressure will become nine times as great. This is an important factor in aëroplane construction as we shall see later. The amount of pressure on a given kite will also depend upon its surface area. If we increase the area faster than we increase the weight we shall add to its lifting power.

Now the effective air pressure upon a kite or a moving plane is always at *right angles* to its surface and can be reckoned as so many pounds per square foot. The amount

of this pressure when the wind is blowing directly against a surface is equal, approximately, to the square of the wind velocity in miles per hour divided by 300. Thus, if we have a wind velocity against our kite of 30 miles per hour, the pressure on each square foot of surface will be $30 \times 30 \div 300 = 3$ pounds. And it makes no difference whether the wind blows against the kite or whether we run with the kite, this pressure at right angles to the surface will be developed. Incidentally we note again, too, that the amount of this pressure increases not simply in the same ratio as the velocity increases but as the square of the velocity.

It is always possible to replace any given force with two other forces that will have the same effect as the single force. If you place a hook in the wall and pull not straight out but in a slanting direction the effect on the hook will be the same as though you were employing two forces—one straight out and one straight down at right angles to each other. If you suspend a weight from a cross bar and support it by two cords placed at an angle to each other the effect is the same as though you employed a single vertical force equal to the weight itself.

Bearing the above statements in mind let us consider the forces in Fig. 57. The line AB represents a kite beine drawn through the air in the direction of the arrow. Thg line DC represents the pressure perpendicular to the kite surface. No matter at what angle the wind strikes the kite the pressure exerted will always be at right angles to the surface. This pressure, too, may always be regarded as concentrated at a single point called the *center* of *pressure.* All the small pressures acting upon the surface due to the wind could be replaced by a single force equal to their sum and acting at this point. Now considering this perpendicu-

lar pressure as concentrated in the single force DC it is perfectly clear that its effect is in two directions. It exerts a vertical lift along EC counteracting the force of gravity and a horizontal thrust along FC which is neutralized by

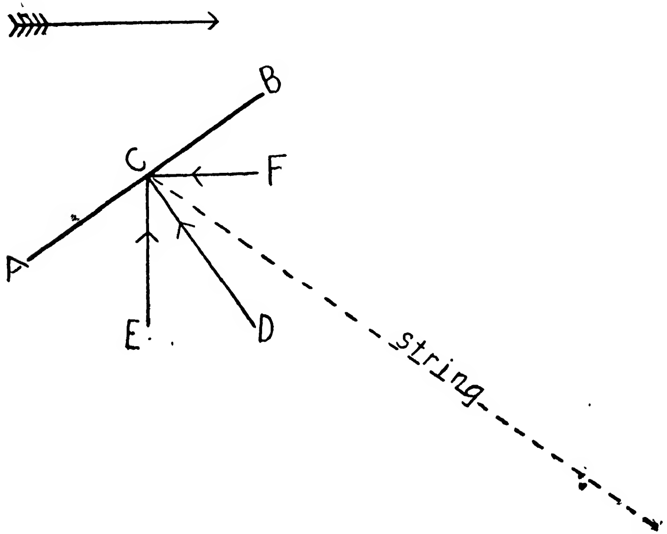


FIG. 57—Forces acting on a kite.

the kite string. If at any moment this vertical force just equals the force of gravity the kite, though moving forward with the running boy, will not rise but will simply stay at that level. If this force exceeds that of gravity and, therefore, is greater than the weight of the kite, the kite will rise. When it becomes less than the weight of the kite, the kite falls. How great this force is depends upon the velocity of the wind or the speed with which the kite is pulled through the air. It depends, too, upon the angle at which the kite strikes the wind. If the kite were horizontal

and the wind blowing in the same direction, i. e., parallel with it, there could be no pressure on its surface.

The Aëroplane.—Now the explanation of the lifting power of an aëroplane is exactly the same as that for the kite. We simply substitute for the string and boy a gasoline motor and drive the plane through the air at a speed of 60 miles an hour, say. Using the same diagram as for the kite, AB will represent one of the two main planes, DC the pressure developed perpendicular to the surface and FC the vertical component of this pressure which counteracts the weight of the machine and lifts it upward. The horizontal component FC is the resistance which the propeller must overcome in driving the machine forward. In starting from the ground the two main planes are set so as not to catch the wind and the motor is started. The machine runs along the ground until sufficient speed has been attained when suddenly the pilot tilts the front edge of the plane upward to catch the wind and the pressure developed will immediately lift it from the ground and carry it into the air. Just as the soaring bird must run along the ground gaining considerable speed before it can spread its wings and mount upward, so must the aëroplane gain speed and pressure before it can fly. So, too, with the glider. Its operator runs with it to gain speed and then jumping downward from some elevation, the pressure on the planes caused by the forward movement and the weight of his body, enable him to glide slowly and easily to a lower level.

A popular way of explaining this gliding of an aëroplane is to say that the mass of air forced beneath the curved surface of the plane exerts an upward pressure tending to sustain the machine and that the forward movement is so rapid that the air literally does not have time to give way before it is replaced with a fresh mass. The effect is likened

to that of a person skating very rapidly over thin ice. If the skater were to stand still the ice would break, but he moves so rapidly that it does not have time to break. While this is a good illustration and may help us to understand why a light fluid substance like air is able to support in perfect security a very heavy machine, it must be remembered that this is only an illustration and does not really explain. If an aëroplane is moving forward in a horizontal direction, the upward lifting force at any moment or any successive number of moments must equal the weight of the machine or else it will constantly fall to a lower level and eventually reach the ground.

The planes of an aëroplane are curved upward so as to enable them better to catch the wind and prevent the air

FIG. 58—Stream line construction.

from escaping underneath so rapidly. This increases the lifting power from one-fourth to one-half. The stream line construction is adopted for all parts of frame and body. The effect of this is seen in Fig. 58. If any portion of the frame is square in cross-section, as it moves rapidly through the air a partial vacuum is created behind and the "head" resistance becomes very great. If on the other hand it is somewhat oval in section and elongated with a sharp cutting edge, the air flows evenly from it and diminishes very much the resistance.

Stability and Steering.—Stability is the most vital factor in successful aviation. In an aëroplane it is of two kinds, longitudinal, or endwise and lateral, or sidewise. By stability we mean the ease or difficulty with which a body may be overturned. In an aëroplane this matter of stability is intimately connected with two points, the *center of pressure* already explained and the *center of gravity*. The center of gravity is the point at which the weight of a body might be regarded as concentrated. If suspended at this

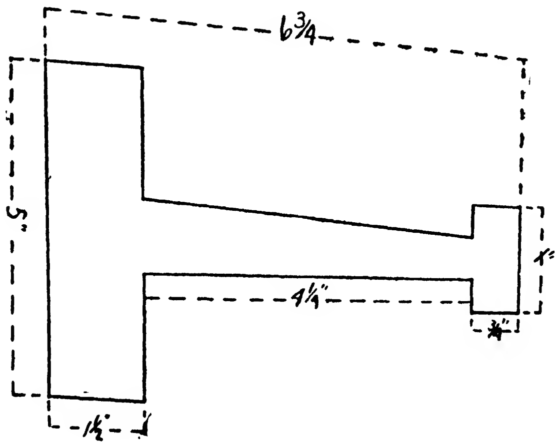


Fig. 59.

point a body will always balance in whatever position it may be placed. Now in order to secure longitudinal stability it is necessary to keep the center of gravity and the center of pressure together or as nearly so as possible.

To illustrate this point cut a piece of bristol board as shown in Fig. 59. Holding it by the small end in a horizontal position let it drop and you will find that it begins to tip and turn and will quite likely fall upside down. Now place

a number of paper clips along the front edge evenly spaced and holding it as before let it drop again. This time it will fall gracefully to the floor without any turning movement. The center of pressure is toward the front of the larger plane and by weighting the front edge we have brought the center of gravity to about the same point.

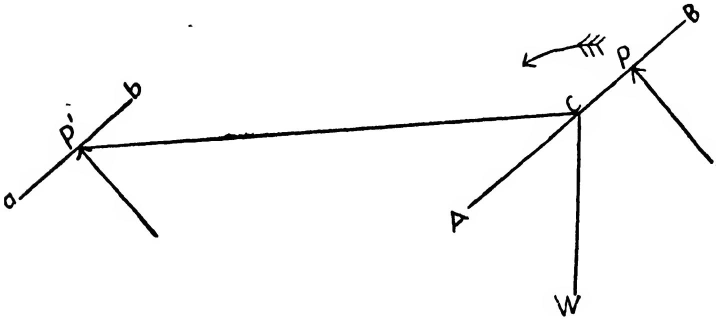


FIG. 60.—Relation of center of pressure and center of gravity to each other.

Why these two points should be together will become clear from a consideration of Fig. 60. The line AB represents one of the main wings of an aëroplane and *ab* one of the horizontal tail planes. Now suppose the center of gravity of the big plane is at C and the center of pressure nearer the front edge at P. The effect of these two forces, the weight of the plane at C and the air pressure at P, is to revolve the whole plane around in the direction of the arrow. But if these two forces were acting at the same point this turn ing effect could not take place.

It will be noted that this turning of the main plane also turns, the tail plane, producing a pressure at P′ and just like a lever this opposes the rotation. Here, too, we see the great stablizing influence of the tail planes set far behind

the main planes. This tail plane is pivoted and by means of wires attached to it is under the control of the pilot who can adjust its inclination so as to make the pressure on it just enough to counteract this effect of rotation. By putting sufficient pressure on the tail plane, too, he can tilt the

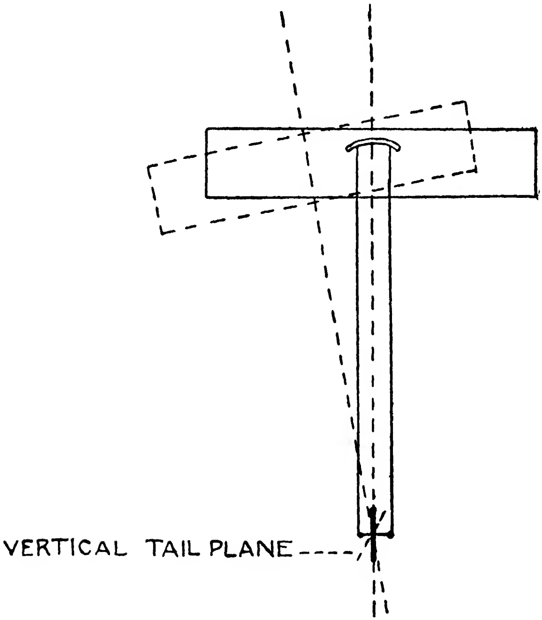


FIG. 61.

main plane so as to bring the center of pressure back to the center of gravity. The position of the center of pressure depends upon the angle at which the plane strikes the wind. The smaller this angle the nearer the front edge of the plane it is.

In ascending to a higher level the pilot tilts the horizontal tail plane so as to raise the front edge of the main plane.

This increases the pressure on the main plane and therefore the vertical component is increased sufficiently to lift the machine. In descending the process is reversed and to maintain flight in a horizontal direction this angle at which the plane meets the wind is made just enough to make the

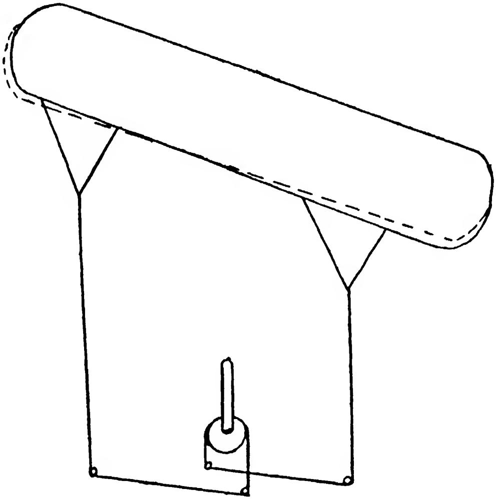


FIG. 62.—Device for warping the wings.

vertical component of the pressure equal to the weight of the machine.

A vertical tail plane under the control of the pilot and acting exactly like the horizontal plane steers the machine to left or right. This is shown in Fig. 61.

The long planes placed crosswise of the machine tend to give lateral stability but very frequently the pressure upon one wing will become greater than that on the other and if not equalized the machine will overturn. The most satisfactory device for accomplishing this is the Wright brothers'

mechanism for warping the wings. A rough diagram of this mechanism is shown in Fig. 62. By warping down the wing on which the greater pressure occurs the effective lifting area will be diminished and the excessive pressure eased. At the same time the other wing is warped up which increases the pressure on this wing with the result that the pressure on the two wings is equalized and the machine righted. Both movements are performed by one operation and at the same time the rudder is turned just enough to keep the aëroplane on its course. Without such a device it would be impossible to make curves, for in flying in a circle the outer wing of the plane moves faster than the inner wing and therefore the pressure upon it is greater and must be neutralized by wing warping or the use of small auxiliary planes called "ailerons." The use of the Sperry gyroscope stabilizer for this purpose has already been explained.

Speed and the Size of the Planes.—Since, if we double the speed of our machine, we multiply the air pressure upon its wings by four it follows that with double the speed we may get the same lifting power with one-quarter the wing area. The early Wright machine had 500 square feet of wing surface and a speed of forty miles an hour. But at 80 miles an hour the necessary wing surface would have been only 125 square feet and at 160 miles only 31¼ square feet. This shows why high speeds are desirable and accounts for the fact that with modern engines of large horsepower aëroplanes can be made so much smaller than formerly. Of especial value is this in military aviation.

Experiments on Aëronautics

Pressure of the Atmosphere.—Secure a tin can—a gallon alcohol can or turpentine can for example—having a smooth

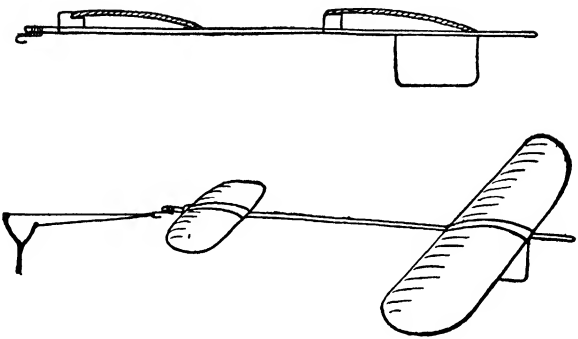


Fig. 64.

rear plane. Planes cut from cardboard or very thin wood may be secured over the elevating blocks by means of rubber bands. Then attach a stout rubber band to an ordinary "bean-shooter" crotch and shoot your glider in the same manner as a sling-shot. Long and graceful flights may be obtained and by adjusting the inclination and position of the planes the glider may be made to perform many interesting evolutions.

A Model Monoplane.—In figure 8 is shown the construction of a fair-sized model flier. The frame consists of two sticks of spruce 36 inches long and ¼ of an inch square separated at the rear by a stream line cross-brace 8 inches long and tapering to a point at the front. A second cross-brace should be placed about one-third the distance from the forward end. These braces may be securely wound to the side beams with silk thread and covered with glue and shellac. The forward ends of the side beams are cut at an angle and glued together. A piece of stout wire having hooks on each end is bent to fit the nose of the frame and secured in place with silk thread and glue. These hooks

will serve for attaching the rubber bands. Two fine guy wires are stretched diagonally between the cross-braces to give greater stability.

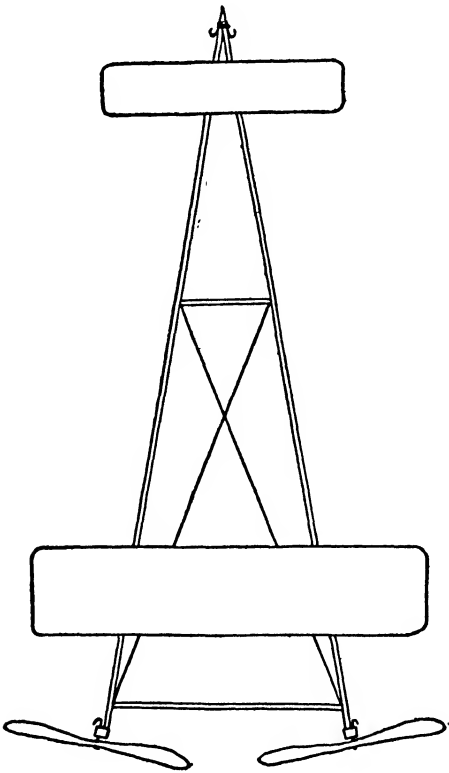


FIG. 65.

The rear plane is made by bending piano wire to shape over a wooden pattern and soldering the ends. This form should be 18 inches long and 4½ inches wide. Two cross-ribs bent so as to arch upward about a half inch from the

horizontal are soldered to the main frame. This frame is then fastened to the side beams with silk and shellac and over it is stretched fine waterproof silk. This covering should be laced tight as a drum-head with silk thread. The forward plane should be 8 inches long, 2 inches wide and elevated so as to make the wings tip upward at an angle of about 10 degrees from the horizontal. A pine board about $^1/_{25}$ of an inch thick may be steamed and bent to shape. It may be secured to the side beams by a stout rubber band or fastened with silk and shellac. The front edge of this plane should be slightly raised by means of elevating blocks placed on the beams.

The propeller blades should be about $8\frac{1}{2}$ inches long, $^1/_{18}$ of an inch in thickness and made of hard wood. They may be cut in outline from a half-inch board and then carved to shape, but it will be more satisfactory to buy ready-made propellers from some dealer. The end of each side beam should carry a brass elbow having a small hole drilled in it for mounting the propeller shaft. A small steel washer must be slipped on the propeller shaft so that it will come between the hub of the propeller and the brass elbow. To reduce friction place vaseline between the moving parts. Shafts much superior to the home-made type may be bought for a few cents.

For each motor use 8 strands of $\frac{1}{4}$ inch flat elastic and give them about 1,000 turns either by hand or with a mechanical winder which may be obtained from any dealer.

A Light-Weight Flier.—Select a stick of spruce or some other light wood 36 inches long and $\frac{1}{4}$ inch square. The main plane should be 16 inches by 4 inches and the smaller one 9 inches by 2 inches. These should be cut from a board $^1/_{16}$ of an inch thick and may be worked down with sandpaper somewhat thinner. Round off the corners. Then

steam the planes and bend the wings upward slightly from the middle. Fasten the planes to the stick with rubber bands until balanced and adjusted and then glue them in place. Cut a propeller blade 6 inches by 1 inch from a half-inch board. Carve this to shape and make it as thin as possible. Mount the propeller as in the previous model and place a hook on the forward end of the stick. Use two or three strands of $^1/_8$ inch rubber for the motor and fly your plane with the wind.

Chapter X

"THE ASSASSIN OF THE SEA"

The submarine, well called "The Assassin of the Sea," is a marvelous product of the inventive genius of the race applied to the evil business of war. A wholly untried factor at the beginning of the Great Struggle, its phenomenal development and unrestrained use in the hands of an unscrupulous and desperate nation, has revolutionized historic methods of naval warfare. Unlike its counterpart of the air its sole purpose is destruction—destruction of life and property on a scale and with a degree of ruthlessness never before practiced by civilized people. The aëroplane and airship will be even more useful in the pursuits of peace than they have been destructive in time of war. But not so with the submarine whose crown of glory has been a felon's blow, her greatest achievement the spread of "frightfulness."

Although left for other nations to develop, the submarine is an American invention. Just as every great invention is preceded by numerous crude attempts to materialize the idea which it embodies so was the submarine. The first of these was by Van Drebble, a Dutchman, early in the seventeenth century. But one hundred and fifty years later David Bushnell, an American, made the first real submarine. This was during the War of Independence in 1776 and its only exploit was an unsuccessful attempt to sink the British man-of-war *Eagle* lying in New York Harbor. This unique craft stood on end, carried a crew of one,

was operated by man power and could remain submerged half-an-hour. Just as in modern submarines, it was submerged by admitting water to the ballast tanks and was brought to the surface by pumping this water out. A lead keel of 200 pounds weight kept the boat in an upright position and could be quickly detached if an emergency should make necessary an immediate rising to the surface.

The next man to interest himself in underwater craft was Robert Fulton, better known as the inventor of the steamboat. In the uncertain financial condition of this country during Washington's administration, Fulton decided to transfer his energies to France. There he succeeded in interesting Napoleon in the project and received financial aid for the construction of the *Nautilus*. In this he adopted the familiar cigar-shaped type and built a boat about 21 feet long, covered with copper and operated like Bushnell's "Turtle" by man power. With this he was able to remain submerged for 5 hours and by admitting or pumping out water could sink or rise at will. Although he succeeded in attaching a bomb to a pontoon structure and blowing it to atoms, he had no opportunity to try his luck with a British warship and Napoleon refused to have anything further to do with the new craft.

Fulton then went to England and was successful in interesting William Pitt, the prime minister, in his new boat. Before a commission appointed for the consideration of the matter Fulton gave a demonstration in which with a charge of 170 pounds of gunpowder, he blew up an old brig detailed for the purpose. His method was to submerge, and coming up under the unsuspecting craft fasten his torpedo to the hull which would be exploded by a clockwork timing device set to operate like an alarm clock at a certain definite time. The naval authorities and commission being un-

friendly to this new weapon of war, Fulton returned to America and very reluctantly applied himself to the perfection of a steamboat. He made a later but unsuccessful attempt to interest Congress and in the War of 1812 one of his submarines made several attacks on a British man-of-war off New London.

In the Civil War the Southern Confederacy made the first successful submarine attack upon an enemy ship during actual hostilities. This crude craft, called a "David" because of its diminutive size in comparison with the "Goliaths" of the Northern navy, could hardly be called a submarine. It moved along the surface with its keel submerged, being able to dive for only a few minutes at a time. On the night of February 17, 1864, one of these little Davids carrying a crew of nine and a spar-shaped torpedo entered Charleston Harbor. Making straight for the Housatonic its torpedo struck the big ship in the vicinity of the magazine and the earthquake-like explosion sunk her in a few moments. The submarine and crew were also lost, and it is hardly possible they could have hoped to escape.

After the Civil War nothing more was done until toward the end of the century. Mr. Thorsten Nordenfelt, a Swedish inventor, next made an unsuccessful attempt at submarine construction. The great obstacle in those days was the lack of satisfactory motive power, but this problem was solved by three of the most timely and important of modern inventions—the electric motor, the storage battery and the gasoline engine. Making use of the first two or these inventions Gustave Zede, a Frenchman, built two undersea craft, the latter of which was 160 feet long, 12½ feet wide, and had a displacement of 270 tons and carried 17½ inch Whitehead torpedoes.

The real initiative in modern submarine construction, however, was taken by two American inventors, Simon Lake and John P. Holland. These men originated and patented the two types which with modifications and improvements are found to-day in every navy of the world. Just as the early work on the aëroplane was done in this country so was that on the submarine, but the purpose of the inventors was totally different from that of the outlaw nation into whose hands this new weapon has temporarily passed.

The Lake Submarine.—Lake's purpose in building a submarine was the direct opposite of war. Realizing the large number of wrecked ships and valuable cargoes lying on the ocean bottom in comparatively shallow water, he conceived the idea of building vessels that should be able to move over the ocean bed and salvage this vast treasure. His first submarine, a very small affair, was built in 1894 and christened *Argonaut Junior*. It was only 14 feet long, 4½ feet deep and 5 feet wide, but it was equipped with wheels for moving over the ocean bed and through a compartment in the bow a diver was able to step outside for salvage work. The depth limit was 20 feet. This first attempt proved a great success and Lake quickly followed it with two other boats each of which was equipped with a gasoline engine. These were very seaworthy craft and could weather the roughest sea. They carried an air supply sufficient for a continuous submergence of forty-eight hours and sleeping accommodations for the crew.

The commercial possibilities of the new craft not being realized, the inventor in 1901 began the construction of a naval submarine. As in the previous types this vessel submerged on an even keel by admitting water to the ballast tanks and rose again by pumping this out and admit-

ting air in place of it. Although equipped with horizontal rudders, like an airship, these were not regularly used for descent and ascent. In rising the pumps must be able to develop a pressure equal to that of the water outside which at a depth of 100 feet is about 60 pounds per square inch. For quick rising in the case of an emergency these submarines carry a false keel of considerable weight which can be released by throwing a lever and this loss of ballast causes the vessel immediately to rise. For running on the surface, which is the true sphere of action except when safety demands submergence, gasoline engines were used. When submerged it is of course impossible to run such an engine because of the insufficient supply of air and therefore electric motors were employed. These were operated from storage batteries and the storage batteries were in turn charged from a dynamo run by the gasoline engine when the submarine came to the surface.

These were the essential features of the Lake submarine as they still are of all such under sea boats. This first submarine was able to make a speed of only 8.5 knots on the surface and 5.4 knots when submerged. The United States being unwilling to purchase the craft, it was sold to the Russian Government and proceeded to Vladivostok.

It may be well at this point to give a brief explanation of how a submarine changes its depth. All submarines are built to run on the surface and because of greater fuel economy and the higher speeds there attainable this is always done except where safety demands submergence. But submergence to any considerable depths can be effected in from two to three minutes. Now any body floating or submerged in a liquid is buoyed up by a certain force. We are all familiar with the fact that it is easier to lift a stone when it is under water than when in the open air. We

know, too, how much heavier a bucket of water gradually grows as we lift it from the water. A block of wood or any other floating body is evidently buoyed up by a force equal to its own weight. Now the amount of this buoyancy is equal to the weight of the liquid displaced whether the body sinks or floats. A cubic foot of water weighs 62½ pounds and therefore a cubic foot of rock when submerged in water will weigh 62½ pounds less than it weighs in the air. If a body floats it must be lighter than the water in which it is placed, i. e., a cubic foot of it must weigh less than 62½ pounds. If the body weighs more than this per cubic foot it will sink. If it weighs less, in order to sink it must displace more than its own weight of water and this is impossible unless it be held down by some additional weight. If a body weighs just 62½ pounds per cubic foot, then its density is exactly the same as that of water and it will stay at any depth it may be put. The material in a battle ship, if put into one solid mass, would weigh much more than an equal volume of water and therefore would sink, but when arranged in the form of a ship we must consider its average weight per cubic foot and this is more than half air. Therefore its average density is much less than that of water.

Now when a submarine is floating on the surface of the sea it must be that its density, or weight per cubic foot, is less than that of water. Likewise when it submerges it must have increased its density to more than that of water. In the Lake type of submarine this is exactly what happens and in all types the density is increased to practically that amount. For this purpose the submarine is provided with large ballast tanks. When on the surface these are empty, but at the command to submerge large valves in the bottom are opened and a rapid inrush of water quickly fills the tanks, driving the air out through valves in the top. The

capacity of these tanks is such that when they are filled the average density of the submarine is just a very little less than that of the outside water. This water ballast is so distributed, too, that the vessel will not pitch but will settle on an even keel. To fill these tanks in a modern submarine requires but little more than a minute. Then with the engines running and the horizontal rudder planes slightly depressed the bow will incline downward from 2 to 5 degrees and the vessel will gently glide to any desired depth. Being of practically the same density as the outside water, it requires but very little rudder to keep the vessel at any required depth or to rise or descend at will.

Submarines are built for maximun depths of from 200 to 300 feet, but they seldom operate at depths of more than 60 or 70 feet and frequently less. The depth to which a submarine may go depends solely upon the strength of its walls, i. e., its ability to withstand the outside water pressure. At a depth of 300 feet this is about 150 pounds per square inch. The pressure inside the submarine is of course but one atmosphere, or the same as that of the air at the surface —15 pounds per square inch.

In a vessel of the Lake type which does not avail itself of horizontal rudders for descending and ascending the density of the submarine must be made greater than that of the water to sink and less to rise. In the latter case the pumps, driven by compressed air, are required to develop a pressure equal to that of the outside water, for the water must be pumped out before the vessel can rise. In most modern types the water is admitted and pumped out at the surface and descent and ascent made by the action of a horizontal rudder in just the same way that an air ship rises and falls. The lightening of a submarine by the discharge of a torpedo suddenly increases its buoyancy and the tendency

to rise must be immediately balanced by taking in more water.

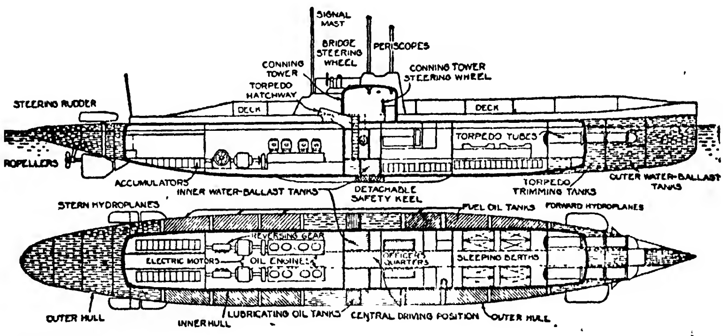
A swimming fish is a natural submarine. By means of an air bladder he increases or decreases his density at will and by the use of fins corresponding to the rudders of a submarine he glides whither he will.

The Holland Submarine.—John P. Holland, an Irish American, is the real inventor of the present type of submarine. The shape of Lake's vessel was very much like that of an ordinary ship and it carried an upper deck of considerable extent. The Holland submarine was of the typical spindle form with very little superstructure and designed entirely for war purposes. Holland built his first boat in 1898. Compared with present day craft it was a miniature affair having a displacement of only 70 tons and making but 5 knots when submerged. This little vessel, however, attracted world-wide attention and was given the severest tests both by our own government and by the representatives of other powers. It began to be realized that the day of the submarine had come and it is worthy of note that the submarine and aëroplane came together. These two great weapons of modern warfare are products of American invention, though foreign nations have contributed very largely to their development and application.

England purchased outright the Holland patents for use in her navy and began the improvement and development of the new type into a very formidable instrument of naval warfare. Our own government, too, adopted this type and although not keeping pace with submarine development in several of the foreign navies, yet has done much pioneer work. The only first class power that seemed to regard the submarine as an experiment of doubtful value was Germany. She waited for developments in other navies and then

established her own works under the direction of the Krupps and proceeded to evolve the Germania or modern U-boat, which is a development from an original French type. At the outbreak of the Great War she was still a third class power in submarine construction and only when Great Britian entered the ranks of her enemies did she turn to the development of the submarine in earnest. The submarines built prior to this time were mostly for coast and harbor defense, having a displacement of 500 tons or less and a cruising radius of less than a thousand miles.

Construction and Equipment.—The construction of a submarine is well shown in the accompanying cuts. The



By courtesy of Scientific American.

FIG. 66.—Construction of a submarine.

hull in some navies is single and in others double. Water ballast is placed both fore and aft and so distributed as to give longitudinal stability. Provision is made for increasing the amount of ballast in exact proportion to the consumption of fuel oil and the loss of weight from torpedo fire. For blowing out these compartments and also for the discharge of torpedoes there are large compression tanks containing air at a pressure of 2,500 pounds per square inch.

The feature which first attracts one's attention on the deck of a submarine is the *conning tower*, sometimes called the "brain" of the vessel. When sailing on the surface its roof serves as the navigating bridge and within it are concentrated the signal and control devices by which the submarine is operated. Here we find the periscope, the wonderful "eye" of the submarine, a repeater from the master gyro-compass below, a number of recording instruments and telegraphs for signaling to different parts of the vessel. Through ports just above the deck line observation may be made in any direction when traveling "awash," i. e., with the surface of the sea just on a level with the deck.

The most vital part of a submarine's equipment is the *power plant*, for upon the capacity and efficiency of this depend its speed and cruising radius. This has been and is to-day the most troublesome problem in submarine construction and operation. The gasoline engine, electric motor and storage battery seemed to offer a solution and while their use has made possible the modern submarine they possess drawbacks.

Because of the insufficient supply of air and the impossibility of exhausting the cylinder gases against high water pressures, it is impossible to use the gasoline engine except for surface running. Therefore storage batteries and electric motors were adopted for submerged traveling. These storage batteries can never be used for more than 20 to 25 hours without recharging, and when running at the maximum speed of 11 to 12 knots they may be exhausted in one hour. Therefore at least once in every 24 hours the submarine must come to the surface and recharge its batteries. This is done by running one of the electric motors backwards as a dynamo by coupling it to the gasoline engine and passing the current into the batteries. This can be

done at the same time that the submarine is cruising on the surface and in spite of the name this is the normal way for a submarine to travel.

For use in confined space a highly inflammable and volatile liquid fuel like gasoline has been found extremely dangerous. It is practically impossible to prevent its evaporation and escape into the air of the submarine where if present in sufficient quantity a spark from the electric motors will ignite it. Gasoline, too, requires high speed engines, is expensive and is consumed at a very rapid rate, thus shortening the cruising radius.

But all these difficulties disappeared with the invention of the *Diesel oil engine.* This is a low speed engine using heavier and cheaper oils such as kerosene and benzol and requires no carburetor or spark coil. On the up stroke of the piston the cylinder is full of air which is compressed to 500 pounds per square inch. This compression generates enough heat to ignite the oil which is sprayed into the cylinder at the top of the stroke. The combustion which follows generates a large volume of gases and raises their temperature to about 3,000 degrees Fahrenheit, shooting the piston downward. An inflow of fresh air immediately follows the escaping exhaust gases, which is compressed on the upstroke and the operation is repeated. Thus this is a two-cycle engine. With this engine the power output is higher, the fuel economy much greater and there is no danger from explosion of escaping gasoline. The Diesel engine is now used on all undersea craft and is one of the greatest inventions of recent years.

For submerged traveling nothing has taken the place of storage batteries and electric motors. One element of danger from the storage battery is the possible leakage of salt water into the cells, which reacts with the sulphuric

acid and lead oxides to form the poisonous gas chlorine. This happened with the United States submarine E2 during the autumn of 1914. The storage batteries are also used for electric lighting, for the operation of the ventilating system and the running of the motors which control the steering gear.

The *periscope* is absolutely essential to the stealthy approach, the fatal aim and the quick get-a-way of this serpent of the seas. Without it the submarine, except when cruising awash, would be as blind as a bat. Although the periscope in crude form dates from 1864, its wonderful perfection has been accomplished during the last ten years. The diagram in Fig. 67, shows the essential features of this instrument. The rays of light from a distant object pass through the objective O and entering the total reflecting prism R are reflected at right angles straight downward through a system of lenses to another total reflecting prism where the rays are again reflected at right angles into the lenses of the observing telescope. The lens system in the tube is for slight magnification, the reinversion of the image and the correction of distortion. Such a periscope gives a range of about 60 degrees in whatever direction it may point and can be rotated through the whole circle of 360 degrees.

It is of course highly desirable to be able to command the whole horizon in one view and for this purpose a periscope with a circular lens for objective has been perfected. This is one of the greatest optical triumphs ever made and has been carried out by English and German opticians working independently of each other. In this periscope there are no less than seventeen sets of lenses to overcome what at first seemed insuperable obstacles of distortion, aberration, etc. The periscope gives a circular field of view including the whole horizon but with a dark spot in the center.

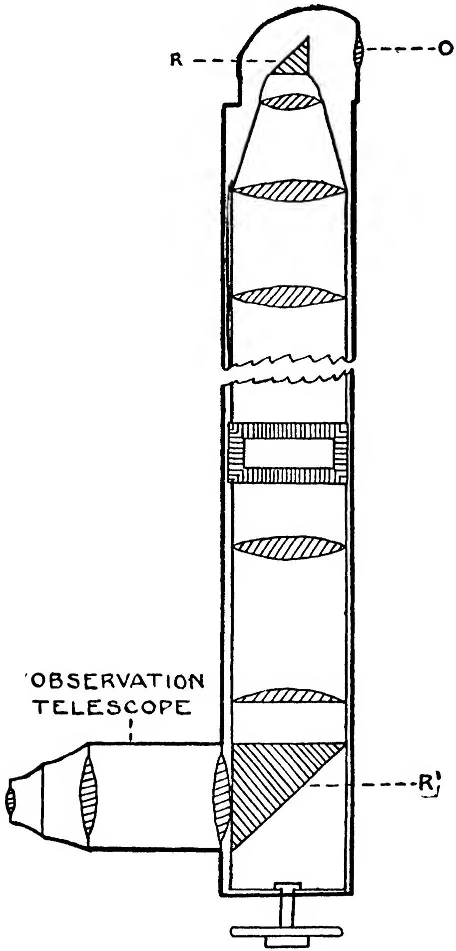


FIG. 67.—A periscope.

To fill this space a direct vision periscope is provided so that in the center is obtained an image of the scene directly ahead of the submarine while about it is a fringe showing clearly every point of the compass. It is possible to throw these images on to a ground glass screen placed beneath the periscope, but this is practicable only in very clear weather and never when exact details are essential.

With the periscope projecting 20 feet above the water a battleship may be picked up at a distance of about 6 miles in clear weather. With the periscope 3 feet above the water the range is restricted to about 2 miles and at 1 foot to barely a mile. At night the periscope is of no value unless the moon is shining brightly and even then its use is very limited. Even when the periscope is shot away water cannot enter the submarine and by means of compass and conning tower escape is assured.

The *Torpedo*, the most deadly projectile of modern warfare, is really a self-propelled submarine in itself. The famous Whitehead torpedo was invented and brought to perfection by a British engineer residing in Austria about the year 1876. As originally perfected this torpedo carried about 26 pounds of gun-cotton and had a speed of 18 knots. Present day torpedoes are from 18 to 21 inches in diameter and about 20 feet long. They carry from 175 to 300 pounds of gun-cotton and have a speed of from 30 to 45 knots. The maximum range is about 6¼ miles.

The shell of a torpedo is made of tough vanadium steel of about a half inch in thickness. The head is filled with the charge of gun-cotton and extending directly through the explosive mass is a steel rod called the "pistol." The inner end is pointed and rests directly against the detonator which lies behind the gun-cotton. The part projecting beyond the nose of the torpedo is threaded and fitted with

a small propeller. As the torpedo is discharged and passes through the water this propeller begins to revolve and unscrews itself from the rod, dropping off at a distance of 150 feet from the submarine. This prevents the premature discharge of the torpedo by coming in contact with any obstacle within the safety zone of the submarine itself. Following the charge of explosive is an air chamber containing compressed air under a pressure of 2,150 pounds per square inch to operate the small four-cylinder engine for propelling the missile through the water. The engine and gyroscope-steering device are in the stern section. Two propellers immediately behind rotate in opposite directions. A small alcohol burner contained in the middle section is ignited just as the torpedo is fired, and by preheating the air before it enters the engine the distance to which the torpedo can be fired is increased to a remarkable extent.

The torpedo tubes are in the bow and stern of the vessel. In loading, their breech locks are thrown open and the torpedo slid into position by machinery. The breech locks are then closed and the officer on duty in the conning tower, having taken the range of his target and set the mechanism for the proper depth and angle, presses an electric button and the deadly missile speeds on its way. The torpedo is discharged by compressed air and just as the discharge takes place a small conical-shaped cap fitting over the torpedo tube swings open. Immediately after the torpedo has passed this cap closes to prevent the entrance of water, but in a compensating tube above, just enough water is automatically taken in to make up for the weight of the discharged torpedo. Contrary to the common idea the torpedo does not travel on the surface but at a considerable depth, depending on whether the target is a large ship or a small destroyer. The best means of detecting its ap-

proach is by observation of the long trail of bubbles which come from the exhaust of the engine, but the torpedo will always be about 100 yards in advance of these. The nose of the torpedo is provided with net cutters which enable it to hack its way, with little loss of velocity, through steel nets placed about a ship. When the torpedo strikes the ship's hull the pistol is driven backwards into the priming charge and the gun-cotton is fired. No ship afloat is able to withstand the terrific violence of such an explosion when struck fairly and squarely.

The largest submarines to-day have a displacement of 1,000 tons. There may be a few larger than these but nothing definite is known of them. The maximum cruising radius is from 6,000 to 8,000 miles, and this is possible only at surface speeds of 11 to 12 knots. With the maximum speed of 18 to 20 knots the cruising radius would be reduced to 1,000 miles. That these ocean-going submarines can cross the Atlantic has been demonstrated by the voyages of the *Deutschland*, the U53 and the submarines that preyed upon American shipping off our eastern ports during the spring of 1918. Convoyed by huge mother ships to supply them with fuel and lubricating oils, there appears to be no reason why a flotilla of ocean cruisers could not cross the Atlantic and, establishing a base in the shallow coastal waters, lie in wait for American shipping at our very doors. So far it has been more profitable for Germany to attack commerce carriers on her own side of the water, and undoubtedly her supply of submarines has been limited and is quite likely growing smaller.

There appears to be no one sure antidote for the submarine. The means of combating it are varied. One method which has accomplished something but not much in the present war is to attack the submarine bases. This would

be the surest and most effectual method and it is not at all improbable that with an overwhelming superiority in the number of bombing planes possessed by the Allies this could be accomplished. Another method is to protect ships by sealing up the entrance to harbors and building ships of higher speeds than are possible with the submarine. The best method has been to hunt out and destroy the submarine wherever it could be found. For this purpose the torpedo boat destroyer has been found very effective. Having a speed practically double that of the submarine, this light craft has been able to run down and destroy by gun fire or ramming very many of the undersea boats. When convoyed by destroyers, battleships and transports are safe from submarine attack and this accounts for the great success of the Allies in ferrying troops during the Great War. Mines probably account for few submarines, and nets stretched across harbors and channels only afford protection for the shipping within. The aëroplane and airship when looking straight down into clear water and with cloudless skies are able to spot submarines, but the possibility of dropping bombs from a moving aëroplane upon a moving submarine is very uncertain. With the immense amount of Allied and neutral shipping entering and leaving the ports of Western Europe every day since this war began, it is most remarkable that more of it has not been sent to the bottom.

For centuries to come this black night of submarine frightfulness culminating in the cowardly crime of the *Lusitania* and a thousand more will brand as outlaws and assassins the government that conceived it and the people who approved it.

That the submarine will continue to increase its efficiency and sphere of action there is little doubt. If an

unscrupulous nation of organized assassins armed to the teeth with submarines and aircraft shall ever again make a surprise attack on the peace of the world, there will be no limit to the conquest that she may make.

EXPERIMENTS ON THE SUBMARINE

The Cartesian Diver.—A very simple contrivance for showing the law of buoyancy as applied to submarines is the *Cartesian Diver*. Secure a glass cylinder similar to the one shown in the cut. Fill it with water and submerge in it mouth down a small pill bottle. The bottle should contain water sufficient to make it *just* float. Then tie over the top of the cylinder a tightly stretched piece of rubber dam to confine the water. Place the palm of the hand on the top of the cylinder and press down gently. The pill bottle will immediately begin to descend and will sink to the bottom. Upon releasing the pressure it will rise to the surface or by adjusting the pressure nicely the diver may be held at any desired depth.

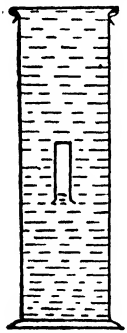


FIG. 68.

Upon careful observation it will be seen that, as pressure is applied to the surface above, the water rises in the bottle slightly, thus increasing its density to more than that of the water and causing it to sink just as a submarine does when it takes on ballast. As the pressure is relieved this water escapes and the increased buoyancy brings it to the surface.

This experiment may be varied by substituting a large bottle with flat sides for the cylinder. Insert the pill bottle and adjust it to almost the density of water. Then cork the bigger bottle tight and it will be found that the diver may be operated by simply compressing the two flat sides of the bottle with the hand.

Flotation.—Secure a tall cylinder and fill it half full of a strong solution of common table salt. Very carefully pour down the side fresh water until the cylinder is full. Now drop into the cylinder an egg. It will settle until it reaches the layer of brine and there it will float. The egg has a greater density than the fresh water but is lighter than the salt water.

Two Liquids of Equal Densities.—Olive oil does not mix with water and being lighter floats on its surface. Fill a small tumbler half full of water and pour into it a little olive oil. Now add alcohol a little at a time with constant stirring and very soon the oil will collect in large spherical globules beneath the surface. These globules will remain suspended at any depth because the density of the alcohol and water mixture has been made equal to their own.

Buoyancy.—Secure some regular solid, heavier than water, as a cement block. Take its dimensions and calculate its cubical contents as a fractional part of a cubic foot. Now with a spring balance weigh the block in air and then in water. Subtract the weight in water from the weight in air and find what fractional part of 62½ pounds this loss of weight in water is. This fraction should be the same as the previous one representing the fractional part of a cubic foot occupied by the block. Why?

Construction of a Periscope.—A very simple device for illustrating the principle of the periscope and one which will have considerable magnifying power can be made in accordance with the illustration in the accompanying figure.

The objective O is a double convex lens of 14 inches focus and 1½ inches diameter. The distance from the center of the lens to the center of the mirror M must be 3 inches. M is 1½ inches wide and long enough to fit the containing tube. Mirrors M and M′ must be exactly parallel with

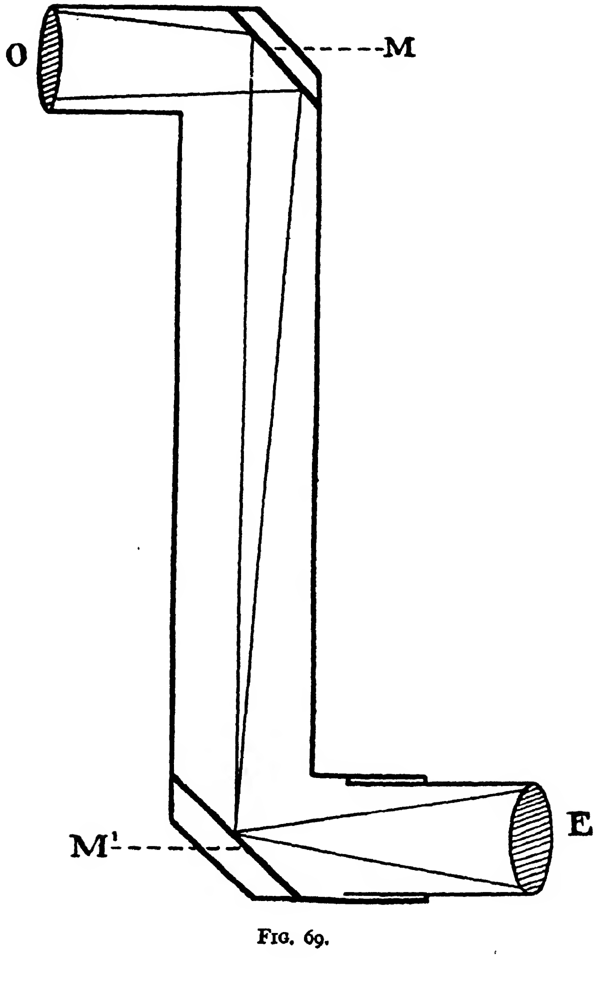


FIG. 69.

each other and at an angle of 45 degrees with the vertical. The distance between them is 11 inches. The eye-piece is a double convex lens of 4 inches focus and 1 5/8 inches diameter. The distance between its center and the center of the mirror is 4 inches. Thin strips of board may be cut of proper size and fitted together for the mounting of the lenses and mirrors. Provision should be made for very slight adjustment of the eye-piece.

The light from a distant object passes through the objective to the mirror M and is reflected to a focus on mirror M′ from which it is again reflected through the eye-piece. In principle this is simply a telescope with mirrors added to change the direction of sight. The image will be inverted.

Chapter XI

THE STORY OF THE STEAM AGE

Written all over the pages of history and interwoven in the fabric of human experience is the drudgery of mankind. By pitifully slow and laborious processes the manpower of the race was for ages harnessed to the performance of its tasks. The pyramids of Egypt are colossal monuments to the infinitude of human toil. Surrounded by unseen forces and great laws of Nature, especially calculated to assist them in the struggle for existence, men in their supreme ignorance plodded on without their aid. Slowly and painfully, as men groping in the dark, someone would discover a new principle, invent some crude mechanism or adapt some natural force to the performance of the world's work. Doubtless by accident the fundamental laws of machines were discovered and put into practical application in clumsy, inefficient devices. Gradually the kinetic energy of moving air and running water was set to turning the wheels of industry and driving the ships across the sea. But up until the beginning of the last century the record of human achievement had been very largely one of religious, political and intellectual development. The world was still primitive. Mountains were insuperable barriers to trade and social intercourse. Oceans were crossed only by tedious voyages in almost miniature sailing vessels. In point of time the world was of immense proportions. The later labor saving devices that have multiplied the manpower of the race by thousands and even millions were

all unknown. The great divisions of labor and the consequent organization of industry were not even dreams. "The coach-and-four" was the fastest means of land conveyance. People lived within themselves. Ideas traveled slowly. Superstitions still beclouded the minds of men. And then at the close of the eighteenth century came James Watt and the steam engine. Not Napoleon and the French Revolution but Watt and the inauguration of the Steam Age with its tremendous industrial revolution are the more important epoch-making events of those momentous times. More than the growth of political ideas the application of steam power in the workshops of the world struck the shackles from the toilers of the race and gave them time to live.

It is safe to say that no other invention can be compared with the steam engine in its influence upon the marvelous industrial and material progress of the last century. Its coming marked a turning point in civilization. But although we have referred to Watt as its inventor, the idea of a steam engine was not original with him. He is rather the genius who taking the ideas of the past and the crude imperfect devices of previous workers, fashioned them into a practical mechanism so far in advance of anything before produced that all the world has unhesitatingly accorded him full credit for the invention. It is true, too, that Watt did invent and perfect the *modern* steam engine.

Like many other great inventions the steam engine had its origin in a long period of previous experimentation. Without going into the details of this early history we shall take up briefly the Newcomen engine, the immediate ancestor of Watt's invention. Thomas Newcomen was a blacksmith, of Dartmouth, England, who in 1705 invented a mechanism for pumping water by the aid of steam. The

device by which he did this is shown in Fig. 70. Steam from the boiler B was admitted to the cylinder C by opening valve V where it lifted the piston. Valve V was then closed and water admitted to the cylinder from tank T

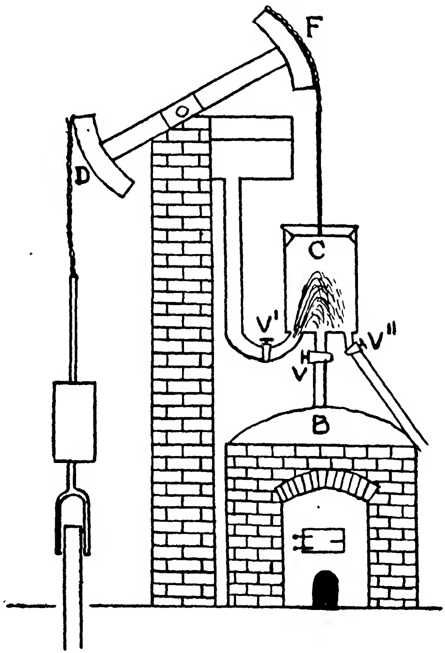


FIG. 70.—The Newcomen engine.

by opening valve V′. This jet of cold water condensed the steam, making a vacuum in the cylinder, and the air pressure acting upon the upper surface of the piston forced it back down. The water was drawn from the cylinder through valve V″. It will be seen that this was more an atmospheric engine than it was a steam engine in any

modern sense. The piston motion was transmitted on through a walking beam FD to a pump rod and made to lift water from mines. It was a very slow and inefficient mechanism at best. The valves at first were operated by hand, but the story is told that a boy named Potter, who had been set to turn these valves, devised a system of cords in an ingenious fashion so as to make the walking beam do the work for him. In any case their action was soon made automatic.

The most serious defect in the Newcomen engine was the great waste of fuel. After each movement of the piston the cylinder was cooled off by the cold water admitted and a considerable portion of the fresh steam was condensed each time before the piston could be raised. But still engines of this type were used for half a century and more to pump water and raise coal from mines and they represented the greatest achievement up to that time in the production of power-driven machinery. Because, too, of the great invention to which it led the Newcomen engine will always have an honored place in the history of steam power.

James Watt, who overcame the defects of the Newcomen engine and developed it into a real steam engine, was a Scotch instrument maker at the University of Glasgow. One day in 1765 there was brought to him for repair a model of the Newcomen engine. The great waste of energy in the alternate cooling and heating of the cylinder was at once apparent to Watt and he set himself to remedy this defect. After considerable experimenting, he hit upon the idea of exhausting the steam into a separate cylinder for condensation. He little dreamed at the time of the tremendous results that would flow from this brilliant idea. But he immediately put it into effect and the product of his first efforts is shown in Fig. 71. The action was the same

as before except that the steam was forced by the down coming piston into a separate cylinder in which a jet of water maintained a partial vacuum. The engine still employed atmospheric pressure and was single acting, but

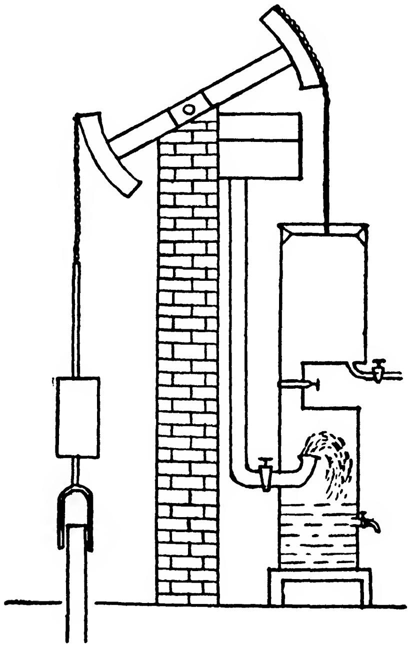


FIG. 71.—Watt's improved Newcomen engine.

the steam was exhausted into a condenser as in modern engines and the great waste of energy was eliminated by keeping the main cylinder constantly hot. To assist in this he insulated the cylinder with wool.

Watt's next great step was to transform his engine from an atmospheric one into a 100 per cent steam engine. He

did this by closing the cylinder to the atmosphere and admitting steam, first on one side of the piston and then on the other. As the steam was admitted on one side, the exhaust valve on the other side was opened and the steam forced into the condensing chamber. To further utilize the energy of the steam Watt cut off the intake of steam each time before the end of the stroke and thus enabled it to expand against the piston. By thus being made to ex-

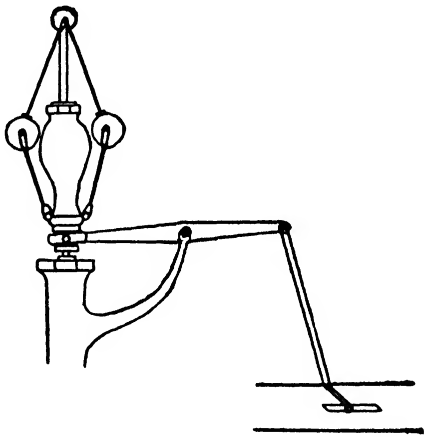


FIG. 72.—Watt's governor.

pand the steam was cooled and gave up a larger proportion of its energy. In other words, it was made to do more work.

Two other improvements must also be attributed to Watt. One is the crank and flywheel for converting the to and fro motion of the piston into rotary motion. The other is the governor for controlling the speed of the engine and keeping it constant. The former did away with the walking beam and connected the piston directly to the shaft which it was to turn. The connecting rod and crank

for accomplishing this, although devised by Watt, were first patented by James Pickard in 1780. The governor shown in Fig. 72 is operated by a belt passing from a small pulley on the crank shaft to another pulley at the foot of the governor. As the engine speeds up, the centrifugal force developed hurls outward the heavy governor balls. This allows the pivoted lever arm AB to rise, which acting through another lever on the valve in the steam pipe partially shuts off the steam and slows down the engine. On the other hand, a sudden increase in the load tending to diminish the speed of the engine weakens the centrifugal force and the governor balls moving in push the lever arm downward and the valve in the steam pipe opens wider, thus admitting more steam to the cylinder. In this way the speed of the engine is automatically kept constant.

Although vast improvements in the details of construction have been made since the time of Watt only two new principles have been utilized in the manufacture of reciprocating steam engines. These are superheated high pressure steam and the compound engine. By high pressure steam is meant steam that has been heated much above the boiling point of water by allowing the steam to accumulate in the boiler and thereby subjecting it to pressure. If water is heated in an open vessel at normal atmospheric pressure it will boil at 100° C. If, however, the steam is confined pressure is exerted on the surface of the water and the temperature of both the boiling water and the steam rise. This simply means that more of the heat energy from the fire below is being stored up in the rapidly moving molecules of the water and steam. The greater the pressure of the steam the greater will be its temperature and the more energy it will possess. Now by building strong boilers and adjusting the safety valve so that the

pressure and the temperature of the steam will be high, we increase many times the quantity of energy that is transmitted to the cylinder and piston of an engine. Then by cutting off the inflow of steam while the piston still has about half of its stroke to make, the confined steam is made to expand to a larger volume and lower pressure, thereby transforming into the motion of the piston a larger proportion of the kinetic energy which has been stored up in it. At the same time this expanding steam does not cool enough to cause it to condense in the cylinder as it formerly did in the low pressure engines. All the heat given up by condensation of steam to water was lost. Of course with high pressure steam the temperature falls as the steam expands and if it did not, no energy would be transformed into motion, but the steam is not cooled sufficiently to cause condensation in the cylinder.

It was early recognized that a tremendous waste of energy was being suffered in the still very hot steam exhausted from the cylinder of an engine. It has come to be axiomatic now that heat is energy and energy is money. A method of diminishing this loss occurred to Jonathan Hornblower, a contemporary of Watt, and in 1871 he patented a compound engine. This principle was improved and is now utilized in all high class reciprocating engines. A compound engine is one employing two or more cylinders, each succeeding cylinder being of a larger diameter than the one that precedes it. As the steam expands in the first cylinder at a pressure of 200 pounds per square inch say, its volume increases and its pressure falls to 100 pounds, perhaps. Now this steam which is still capable of exerting a high pressure is not condensed as formerly, but is passed into a second cylinder of twice the size of the first and made to expand again and drive another piston. Here its pressure

again falls to perhaps 50 pounds and it is passed into a still larger cylinder and made to do more work. Sometimes a fourth cylinder is added, but whatever the number, the steam is exhausted from the last into the condenser where a high degree of vacuum is maintained.

Thus high pressure steam and the compound engine have succeeded in utilizing a far larger proportion of the latent energy in fuel. But the best quadruple expansion and condensing engines are not more than 20 per cent efficient and the ordinary locomotive is only 8 per cent efficient. In other words, in the locomotive 92 per cent of the energy in the fuel is wasted. When we consider, too, that of the billion tons of coal mined annually throughout the world, half of it is burned in the furnaces of steam boilers we see what an enormous waste there is, even in the best of mechanical devices.

The action of the steam engine will become clear from a consideration of Fig. 73. The steam enters the steam chest and passing into the cylinder through the right hand steam port drives the piston to the left and the waste steam on the opposite side of the piston is forced underneath the slide valve and through the exhaust pipe into the condenser. As the piston continues to move to the left the slide valve at the same time moves to the right, closing the right steam port and allowing the confined steam to expand and do its work. When the piston has reached the end of its stroke the slide valve has uncovered the left steam port and the inrushing steam drives the piston to the right and forces the waste steam under the slide valve and into the exhaust. The to and fro motion of the slide valve is produced by means of the eccentric. The eccentric consists of a disk placed on the shaft so that it is off center. Around this disk is bolted two straps connected with the eccentric rod

and in which the disk revolves. Then as the shaft an eccentric disk revolve a to and fro motion is given to the eccentric rod and slide valve. This is so set as to make the

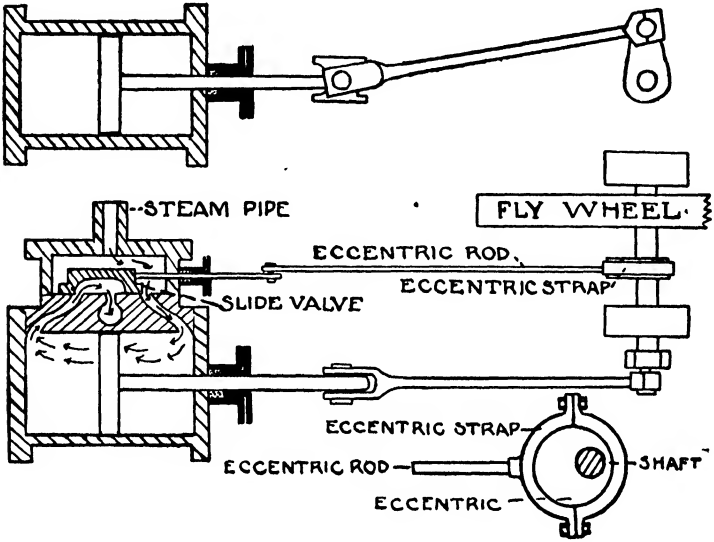


FIG. 73.—The construction of the steam engine.

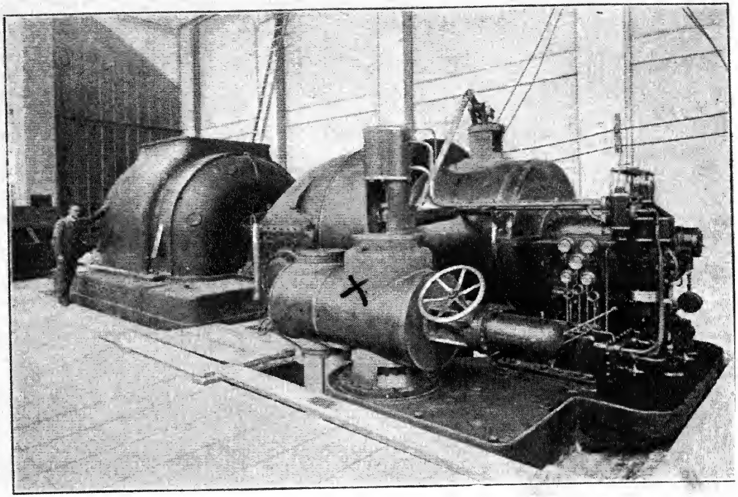
slide valve uncover the steam ports for the supply and exhaust of steam at the proper times.

The immediate need of England at the time Newcomen and Watt made their great inventions was for an increased production of coal. The shallow mines had become exhausted and the man power and horse power of the industry were inadequate to raise the coal rapidly enough from the deeper mines to meet the increasing demands for fuel. Therefore the first task assigned to these new recruits in the ranks of industry was to pump water and lift coal from

the mines of the kingdom. By the beginning of the last century they had also been set to running the machinery in all sorts of mills and doing much of the work formerly done by wind and water. That tremendous expansion of industry characteristic of the Age of Steam, an age in which we still live, was just begun.

The First Steamboat.—One of the first effects of this new found power was to stimulate a widespread interest in applying it to improved means of travel and transportation. As was natural these first efforts were directed toward solving the problem of steam navigation. Just as in the case of the steam engine itself a considerable number of men made contributions to this invention. The Marquis de Jouffroy in France, Symington in Scotland, and Fitch, Rumsey, Stevens and Fulton in this country, all built more or less successful steamboats. But just as Watt perfected the steam engine, so Fulton with his now famous *Clermont* was the first inventor to perfect a steamboat that, against tide and wind, could propel itself at a fair rate of speed for any great distance. On August 7, 1807, this "fire-belching monster" steamed up the Hudson and to the amazement of all and the alarm of many made the trip from New York to Albany in 32 hours. Epoch making was this event, for it numbered the days of the sailing vessel.

Steam navigation was rapidly applied to rivers and lakes. In 1809 the traveler could go by steamboat from Philadelphia to Bordentown with breakfast and dinner on board. From there he took the stage to New Brunswick where he stayed overnight and continued his journey to New York the following day. A tedious way of travel we should say now and yet we can imagine the delight with which it was hailed in those days of the stage coach and ox-cart.



Steam turbine and 7,500 kilowatt alternating-current generator.

In 1819 the *Savannah*, the first steamship, crossed the Atlantic, although not depending upon steam power altogether and using her sails for part of the voyage. In 1838 the *Sirius* and the *Great Western* made the passage with steam alone. A speed of over 200 miles a day was made by the *Great Western* and about 450 tons of coal were consumed. The *Britannia*, the first steamship of the Cunard Line, started on its maiden voyage across the Atlantic on July 4, 1840. Very soon steel vessels began to replace the old wooden ships. Larger and faster ships were built. Screw propellers took the place of the side-wheel boats. The "ocean greyhounds" appeared in 1871 and by 1888 the time of passage from Europe to America had been cut to less than six days.

The Steam Turbine.—Another and more recent application of steam, which has had a very great influence on the development of ocean steamships, is the steam *turbine*. This engine makes use of the direct impact of the molecules of steam on a large number of little curved blades attached to the circumference of a disk mounted on a long slender shaft. Although there are three principal types of steam turbines, the DeLaval, the Curtiss and the Parsons, they all utilize the same fundamental principle and translate the kinetic energy of the steam directly into the motion of the turbine.

The turbine was invented by Mr. C. A. Parsons of England in 1884 and has had a very rapid development. In this type the rotating spindle carries several sets of blades, each set being longer than the preceding. The casing that fits over the spindle carries an equal number of sets of stationary blades, which dovetail in between the moving blades. The steam enters the turbine on the side of the shortest blades at a velocity frequently of 4,000 feet, or

three-quarters of a mile per second. By direct impact the molecules of steam set the spindle rotating and the steam glancing from one row of moving blades is guided by the adjacent stationary row so that it strikes the next moving row at just the right angle and so on to the opposite end of the spindle. As the steam moves forward it expands and its pressure falls. Therefore, just as in the compound engine, each succeeding set of blades is longer than the set before it. The steam at a very low pressure passes from the large end of the spindle into the condensing chamber.

In the turbine the efficiency is slightly higher than in the reciprocating engine. There is practically an entire absence of noise and vibration and the speeds obtainable are very great, in some small engines being as high as 30,000 revolutions per minute or 500 per second. This seems incredible and yet it is true. These features have especially adapted the turbine for use on ocean liners, and the fastest and largest ones are now equipped with this engine. Among the first large ships to be so equipped were the Cunard liners, *Carmania*, *Mauretania* and the ill-fated *Lusitania*. One objection to the turbine is the impossibility of reversing it and for this reason two sets of engines must be carried, one for direct forward motion and the other for reversing.

The turbine is also used extensively for land installations, especially in electric power plants. The author saw in the United States Steel Company's plant at Gary, Indiana, a large 5,000 horse-power Curtiss steam turbine running on waste steam obtained from the cooling water about the doors of the open hearth furnaces.

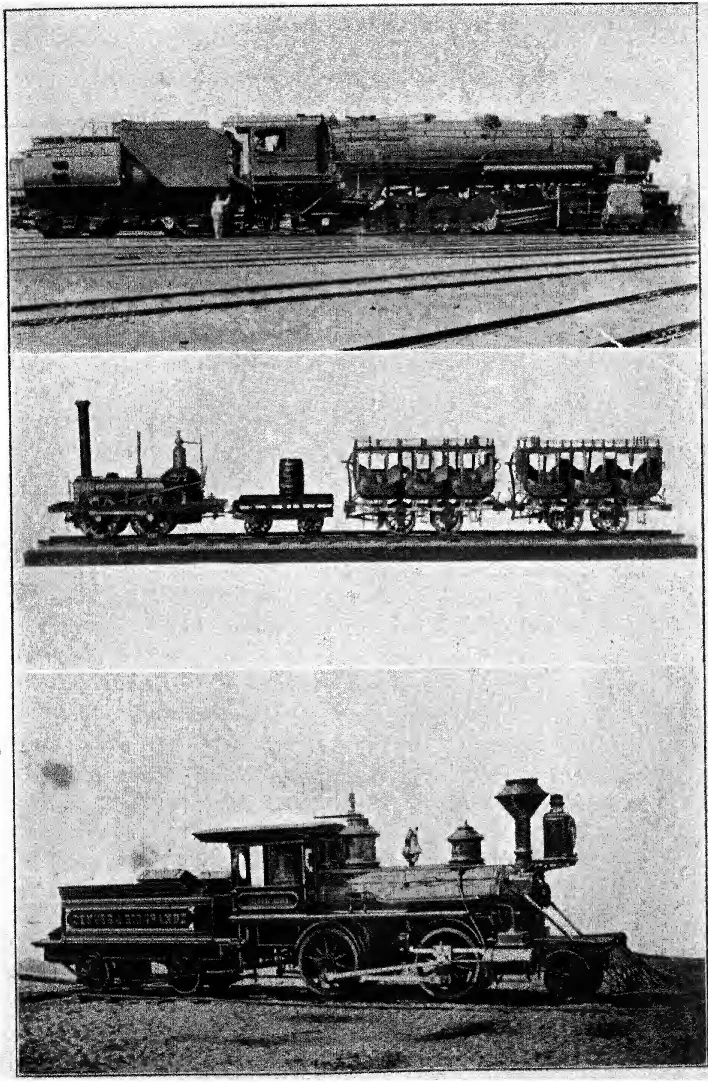
The Locomotive.—Again just as with the steam engine and the steamboat to no one man is due sole credit for the invention of the locomotive. Before the close of the eighteenth century a great variety of experimental locomotives

had been built, but nothing of importance appeared until Trevithick in 1802 produced a steam locomotive that successfully hauled a wagon load of people over the streets of London. Two years later he built a locomotive that was able to draw loads of ten tons of iron, but it was a financial failure and soon abandoned.

The man who built the first successful passenger carrying locomotive was George Stephenson. He was the son of poor parents and from a lad up had worked in the colliery. At eighteen he had risen to the position of fireman and his great ambition was to master the intricacies of the steam engine and to gain a thorough working knowledge of its parts. His knowledge soon became so complete that he undertook the building of an engine for his employers. The result was a locomotive that would haul a load of 30 tons at 4 miles an hour up a grade of one foot in 450. His second locomotive was an improvement but still very imperfect. In 1825, however, Stephenson built the *Rocket* which will forever be recognized as the first thoroughly successful locomotive and the one that converted a long doubting public into rather reluctant support of steam locomotion.

In 1829 the now famous Liverpool and Manchester Railway offered a prize of £500 for a locomotive that on a certain day would best perform certain specified duties. Stephenson entered the contest with the Rocket and in competition with three others established the superiority of his locomotive. With it he performed marvelous feats for those days. Carrying a load of 36 passengers he made a speed of 30 miles an hour and with 13 tons of freight he covered 35 miles including stops in one hour and forty-eight minutes. The world then knew that the age of steam locomotion had come.

The United States with its vast reaches of new country, its poor roads and inadequate transportation facilities offered a rich field for the activity of the locomotive pioneer. The American people were quick to appreciate the advantages to be derived from this new means of travel and there began with the second quarter of the nineteenth century that period of railroad development which has been one of the marvels of modern industrial achievement. The first road to be operated was the Baltimore and Ohio. It was chartered in 1827, the ground was broken in 1828 and the first locomotive, built by Peter Cooper, ran over it in 1830. In the same year six miles of the Charlestown and Augusta Railroad were opened and in 1831 the Mohawk and Hudson Railroad began passenger service. The famous "John Bull" locomotive of the Camden and Amboy Railroad was built in England and received in Philadelphia in 1831. Mr. Dripps, the master mechanic of the road, put it together. He found a four-wheeled car for tender, a whiskey cask from a nearby grocery served for water tank and the locomotive was soon in active service. Locomotive works and railroad shops sprang into existence. The mechanical genius of the country devoted itself to the improvement of the original types of locomotives. Lines of railroad multiplied. New regions were made accessible. The Ohio Valley became tributary to the Atlantic Seaboard. In ten years 3,000 miles of steam roads were in operation and a period of national growth and industrial expansion without parallel in the world's history had been inaugurated. The railroads crossed the Alleghenies, spread like a network over the Mississippi Valley and penetrated the "Great West." They made possible a nation extending from ocean to ocean and when on May 10, 1869, the golden spikes completing the Union Pacific Railroad



Mountain freight locomotive, "John Bull" locomotive and first engine used on the Denver & Rio Grande Railroad.

were driven the East and West were forever united and the first stage of American railroading had passed into history.

Steam power has conquered the world. Under its influence industry has been revolutionized, continents

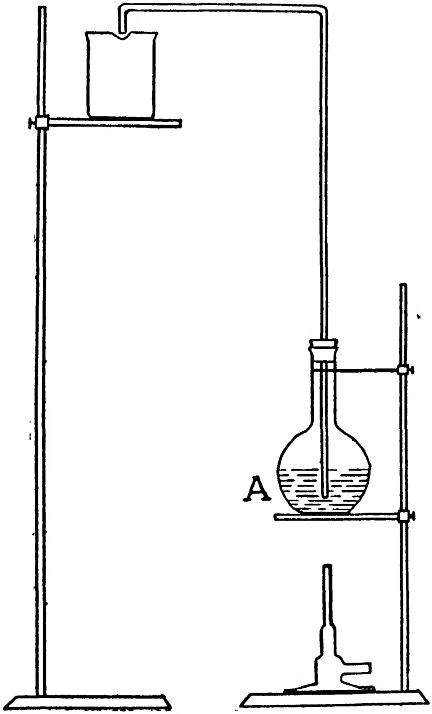


Fig. 74.

spanned, oceans bridged and mountains tunneled. The vastness of the earth has disappeared. Natural barriers no longer exist. Provincial narrowness has broadened into cosmopolitanism. A new era of world-wide political, industrial and social intercourse is about to dawn upon the

earth. But let us remember that back of this wonderful century of human progress stands James Watt and the steam engine.

Two Experiments.—1. That heat is energy and can be made to do work may easily be shown by arranging apparatus as shown in Fig. 74. As the water in flask A is heated, the vapor and air above it expand and pressing downward upon its surface lift the water and cause it to flow in a steady stream into the beaker above.

A one-holed rubber stopper must be used for the flask. To bend the glass tubing place it in a Bunsen burner flame (having a fish-tail top if possible) and rotating it rapidly with the thumb and forefinger thoroughly soften the glass. When this has been done remove it and quickly bend to the desired shape.

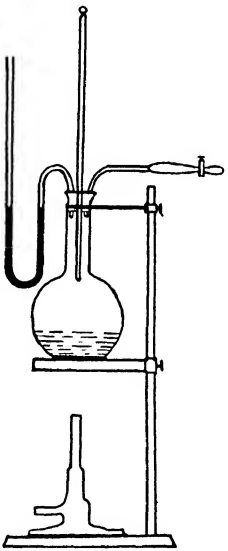


Fig. 75.

2.—Arrange a flask carrying a three-holed rubber stopper with mercury pressure gauge, thermometer and outlet tube as shown in Fig. 75. To the outlet tube attach a short piece of rubber tubing and wire it on with pliers. On this place a screw pinch cock. Heat the water in the flask and when it is boiling freely note the temperature on the thermometer. Being open to the air the water will be boiling under atmospheric pressure. Now cut off the outlet by screwing down the pinch cock and allow the steam pressure in the flask to increase. Three effects will be noted. The water ceases to boil, the mercury rises in the open arm of the pressure gauge and the

temperature indicated by the thermometer increases. The steam is now in the superheated condition. By allowing the steam to accumulate and the pressure to increase, more energy and a higher temperature are required to boil the water. The water will again start to boil but at a higher temperature.

When the temperature has risen several degrees, unscrew the pinch cock and open the outlet. Again three effects will be noted. The mercury falls in the pressure gauge, the thermometer suddenly drops to the former boiling point and the pent up heat energy in the water manifests itself by causing an exceedingly vigorous boiling. This energy is expended in a very rapid transformation of water into steam.

The high pressure steam used in engines is superheated in this same way.

As it is usually impossible to buy three-holed rubber stoppers, a two-holed stopper may have an additional hole bored with cork borers. To do this select a borer of proper size, cover the lower end with thin soap paste or dip it in a strong solution of washing soda and with the large end of the stopper resting on a solid support drill the hole.

CHAPTER XII

SOLVING THE SMALL POWER PROBLEM

If we were to single out any one invention of the last forty years and designate it as having been in larger measure than any other of fundamental importance to the wonderful progress of this period, we should unhesitatingly name the gas engine, or internal combustion motor. And we say fundamental because so many other of the epoch making inventions of this period are dependent upon it and were impossible until it came. A little consideration of what the gas engine has done will make this evident. It has made possible the automobile, the aëroplane and airship, the submarine, the motor boat, the farm tractor, the army motor truck, the motor-cycle, the small power and electric light plant with all that these inventions have meant for weal or woe to the commercial expansion, comfort and happiness of the world. The gasoline motor, the most important type of this class of engines, with a rapidity never before equaled, has come into universal use. It has touched the lives of the common people at innumerable points and has met with perfect satisfaction a host of very real needs. Just reflect for a moment upon what the world would have missed during the last twenty-five years with out this wonderfully efficient, light and powerful little motor and you will only just begin to appreciate its immense importance to the modern world. The steam engine met the big power needs but not the little ones. It was not every man's engine. There was still a multitude of tasks

that it could not perform. It was not light, compact and portable with steam always up and ready to start at a moment's notice. But just when the steam engine was approaching the limits of mechanical perfection and for nearly a century had been solving the big power problems of the world, there came this miracle of modern invention to relieve still further the drudgery of mankind.

Seldom does one inventor enjoy the monopoly of any particular field of investigation. Numerous experimenters are always at work entirely independently of each other and long periods of research and many crude imperfect models usually precede the production of a practical and successful machine. To this rule the gas engine is no exception. As early as 1807 Sir George Cayley, who also worked out the principles of aviation, devised a hot air engine, but the mechanical difficulties were insurmountable and it had no commercial success. In 1824 and later in 1852 John Ericsson, who built the famous iron-clad monitor during the Civil War, constructed hot air engines of considerable size, but they were of small horse power and did not prove successful. Even as early as the seventeenth century the Dutch scientist, Huyghens, and the Frenchman Papin, endeavored to utilize the mechanical energy of exploding gunpowder to operate an engine but without practical result. The first man to invent a real gas engine was the Frenchman J. J. E. Lenoir, who in 1860 patented an engine on the plan of its steam predecessor. The first commercially successful gas engine, however, and the modern four-stroke motor was invented by two Germans, Otto and Langen, in 1866. A very great improvement was made by Otto in 1876, when he introduced the expedient of compressing the mixture of gas and air before exploding it. This added very much to the power and efficiency of the

engine and when a little later it was found that liquid fuel could be substituted for gas, the new era of the light weight, high speed gasoline motor was at hand. The Diesel engine, employing heavier oils than gasoline, is described under the submarine.

The fundamental difference between the steam engine and the gasoline motor is in the liberation and transmission of the energy that drives them. In the steam engine the energy of the burning fuel is transferred into the steam of the boiling water and transmitted to the working cylinder where by impact and expansion it drives the piston. But in the internal combustion engine, as its name signifies, the energy from the exploded mixture of fuel and air is liberated right in the cylinder and immediately exerts the kinetic energy of its moving molecules directly upon the piston-head. This is one of the chief reasons for the higher efficiency of the gasoline engine. Nothing intervenes between the liberation of the heat energy and its application. But the steam engine wastes heat. Not all of the energy in the coal gets into the water. The firebox and hot clinkers radiate to the air a great deal of heat. The boiler radiates more and the steam pipe and cylinder of the engine do the same. All the steam that escapes to the condenser carries away just that much energy, and the hot combustion gases from the firebox carry up the stack far more energy than is transmitted to the water. At best only a small portion of the energy in the fuel is caught and turned into power units by the engine. Then, too, of the horse power delivered by any engine there are large losses in transmission to moving machinery. The percentage of the original energy that is finally translated into really useful work is exceedingly small. And although this lost energy is not destroyed, it is wasted and so far as we are able to see will

never again be available for doing useful work on this planet. It has been absorbed by the great ocean of ether that surrounds us. That there should be in spite of such appalling waste, sources of energy sufficient for the world's needs throughout the centuries that have been and are to be, testifies to the prodigality of nature as nothing else could.

There are two general types of the gas engine, the two-cycle and the four-cycle, or better the two-stroke and the four-stroke. In the former case an explosion occurs every revolution, or every two strokes of the piston, while in the latter there is an explosion but once for every two revolutions, or four strokes. With the two-cycle engine the crank shaft receives an impulse at each revolution, while with the four-cycle engine the impulses are only half as frequent, there being but one for every two revolutions. The two-cycle engine would seem to be more efficient and to develop more power, but such is not the case. It does run more smoothly and with less vibration and does not require so heavy a flywheel as the four-cycle, but for reasons that will be apparent later it is not so well adapted to large power needs. For motor boats and the numerous uses to which small motors are put the two-cycle engine has been very popular.

The Two-Cycle Engine.—The construction and operation of a two-cycle engine will become apparent from a consideration of the diagrams in Fig. 76. We will start with the piston as shown in position A and the cylinder free from gas. If we turn the crank shaft in the direction indicated by the arrow, when the piston has reached the lowest point of the stroke and begins to move upward a partial vacuum will be created in the engine base B and through the valve V a mixture of gas and air from the carburetor will be pumped in. Then as the piston moves downward the gas

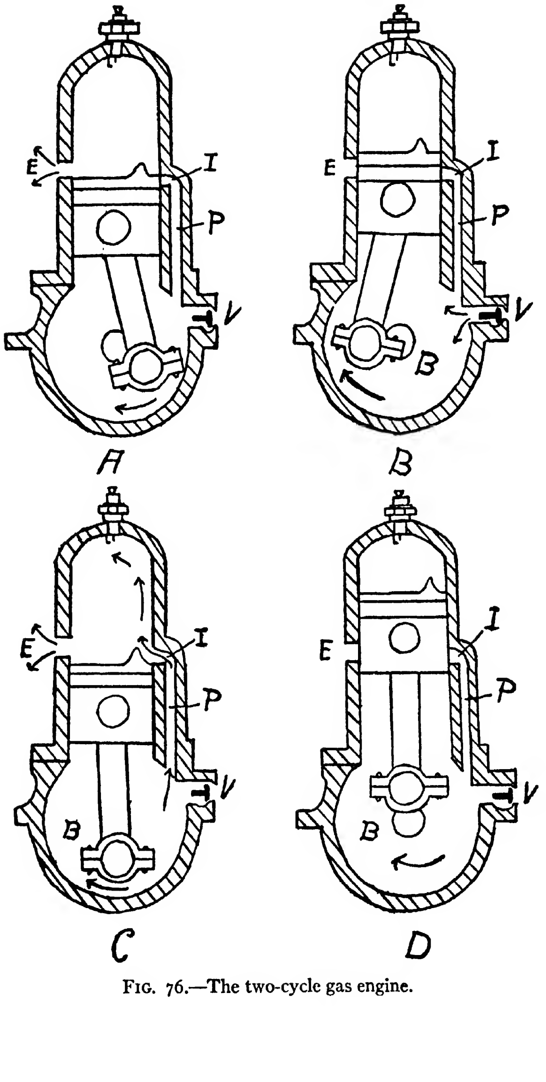


FIG. 76.—The two-cycle gas engine.

in the engine base is compressed and the valve V closed. When the piston has moved to the bottom of the stroke the intake port I is uncovered and the mixture in the bottom being under pressure is forced upward through the by-pass P into the cylinder above. It is prevented from passing directly across and escaping through the exhaust port by the deflector on the piston-head. As the piston now moves upward, as shown at D, both ports are closed and the gas in the cylinder is compressed. When the piston reaches the top of the stroke an electric spark across the terminals of the spark plug ignites the mixture and the large volume of very hot gases which results forces the piston downward. As the piston moves downward the exhaust port is uncovered, first allowing the combustion gases to escape, and immediately following the intake port is uncovered, drawing a fresh mixture into the cylinder. This condition is shown at C. The momentum of the flywheel carries the piston upward and at the top of the stroke a second explosion occurs with the repetition of the "cycles" of change. Thus there are only two cycles, the compression stroke and the firing stroke. On the upstroke a fresh mixture of gas and air is drawn into the engine base below and the mixture above is compressed. On the firing stroke the hot combustion gases expand, shooting the piston down and compressing the mixture below. The compression of the mixture in the cylinder on the upstroke, however, is several times greater than it is in the engine base on the downstroke.

While the two-cycle engine is very simple in construction and operation, it will be seen that a full charge of fresh mixture uncontaminated with burnt gases is difficult to secure. The burnt gases leave the cylinder from their own expansion and some will always be left to mix with the fresh charge. The amount may be considerable and to just

that extent dilutes the charge and lessens the energy liberated on the explosion. Then, too, in spite of the deflector on the piston-head a portion of the incoming gas may escape with the exhaust gases and this loss will lower the efficiency. To build a two-cycle engine is a more difficult task and requires more accurate designing than the construction of a four-cycle engine. Therefore for most purposes the latter type of engine has been adopted.

The Four-Cycle Engine.—The operation of the four-cycle engine is shown in Fig. 77. It will be noted that the intake and exhaust ports are opened and closed by tight-fitting valves instead of by the movement of the piston over them. Starting with the suction, or charging stroke, the intake valve opens and the piston moving toward the open end of the cylinder draws in a charge of gas and air from the carburetor. At the end of the stroke the intake valve closes and the piston moving backward compresses the explosive mixture to small volume. At the point of maximum compression a spark across the terminals of the spark plug ignites the mixture and the piston is forced outward. Just before the end of the expansion stroke the exhaust valve is lifted and as the piston moves backward the burnt gases are swept from the cylinder. At the end of the stroke the exhaust valve closes and the cycle of changes is repeated; thus there is but one power stroke for two revolutions and to carry the piston through the idle strokes a heavy flywheel is required.

In the early engines the intake valve was opened by the suction from the charging stroke, but both intake and exhaust valves are now operated by cams and push-rods. The cam for this purpose is a small metal disk mounted on a shaft and having a projection on one side. This shaft is geared to the flywheel shaft so that it will turn only once

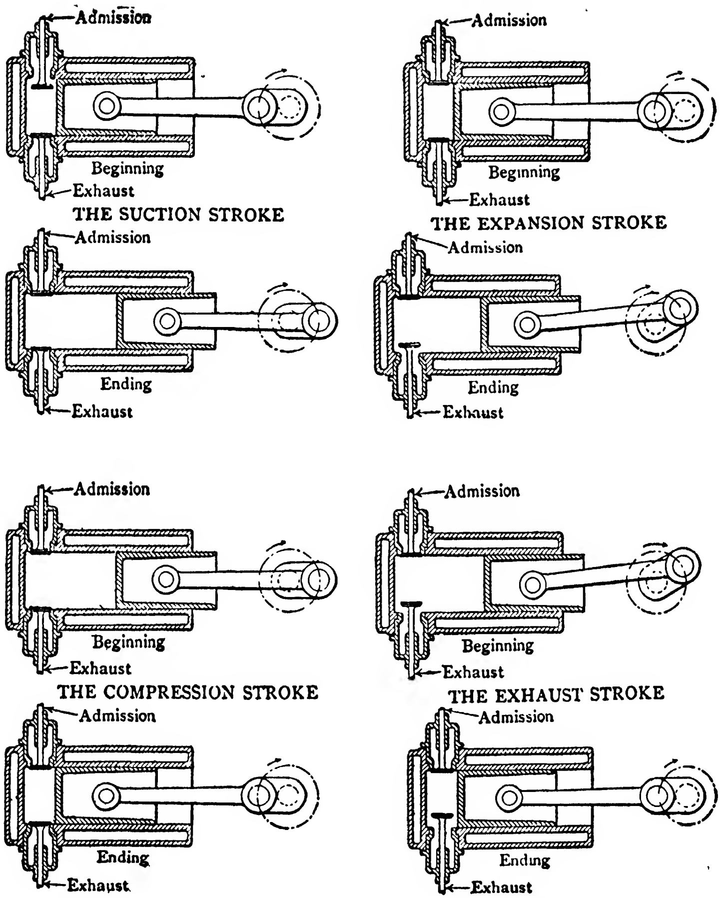


FIG. 77.—The four-cycle gas engine.

for every two revolutions of the main shaft. At the proper instant for the opening of the valve the projection on the cam disk strikes on the push-rod and lifts the valve. A spring brings the push-rod back and the valve closes.

It would be impossible to make a plain smooth piston that would be perfectly gas tight under the very great pressures developed in the cylinder of a gas engine. Therefore pistons are made with several grooves cut in them into which piston rings are fitted. A piston ring does not form a complete circle. The ends do not quite meet and the ring is made slightly larger than the inside of the cylinder. As these rings expand they press snugly against the walls of the cylinder and prevent the gas from leaking out. Pistons, rings and cylinders must be exceedingly true and to make them so has been one of the most important points in gas engine construction. Any leakage results in loss of compression and diminished power.

The heat generated by the combustion in the cylinder is so great that its walls and the piston would become red hot if some provision were not made to cool them. Many two-cycle engines are air-cooled. The cylinder is ribbed to present a large radiating surface and the flywheel shaped like a fan drives a current of air over the hot parts. A water jacket surrounds the cylinder of a four-cycle engine and either by pump or natural circulation water is made to flow about the cylinder to carry away the excess heat. Of course all the heat carried away in this manner is lost energy, but it cannot be avoided.

The Carburetor.—The carburetor is the mechanism in which the gasoline vapor and air are mixed in proper proportions to form a highly explosive mixture. In Fig. 78 are shown a diagram of a simple carburetor and the "model A" Shebler carburetor. The gasoline flowing downward from tank T enters the float chamber and lifting the float F, which may be either of cork or a hollow metal float, closes the needle valve. The gasoline rises to the top of the spray nozzle S and the air being drawn in by the suction

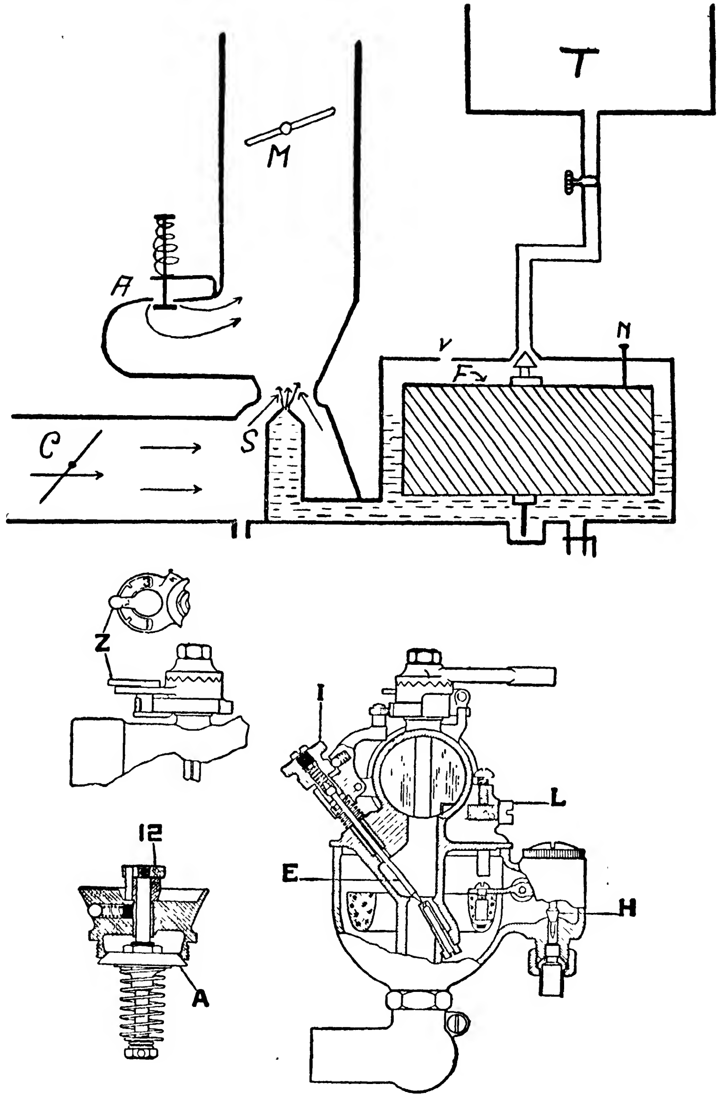


FIG. 78.—The carburetor.

from the cylinder vaporizes the gasoline and mixing with it passes on to the intake manifold of the engine. As the gasoline is used up the float falls, admitting more gasoline and thus the supply is automatically regulated. The intake of air can be controlled by the check valve C. When the engine is running rapidly and working hard not enough air is supplied through the main inlet and therefore an auxiliary air inlet is provided at A. Under these conditions the suction increases and becomes strong enough to open the valve at A and draw in an additional supply of air. By suction is of course meant the diminished pressure in the engine cylinder produced by the charging stroke. The quantity of gases admitted to the cylinder can be regulated by adjusting the throttle valve M. This is frequently done automatically by a governor and the speed of the engine thereby controlled. For increasing the supply of gasoline as is sometimes required in starting an engine the small priming pin resting on the top of the float may be forced down, thereby opening the needle valve. Upon the proper adjustment of the carburetor depends the proportions of gas and air and the explosive qualities of the mixture. Therefore to a very large extent the efficiency of the engine is a function of the carburetor.

The Ignition System.—To produce the spark necessary to ignite the mixture of gas and air two main systems are employed—the *storage battery and induction coil* and the *magneto system.* The construction and action of both the storage battery and induction coil are explained in other portions of this book and it will be assumed that their use is understood. A simple ignition system of the first type is shown in Fig. 79. The main shaft is represented at W and geared to this is the cam shaft W′. The number of cogs on the main shaft is half that on the cam shaft and there-

fore the latter makes only one revolution for every two of the main shaft. An insulating disk D is mounted on the cam shaft carrying a brass contact and screw at K. Back of this disk is mounted a movable plate M. P. which car-

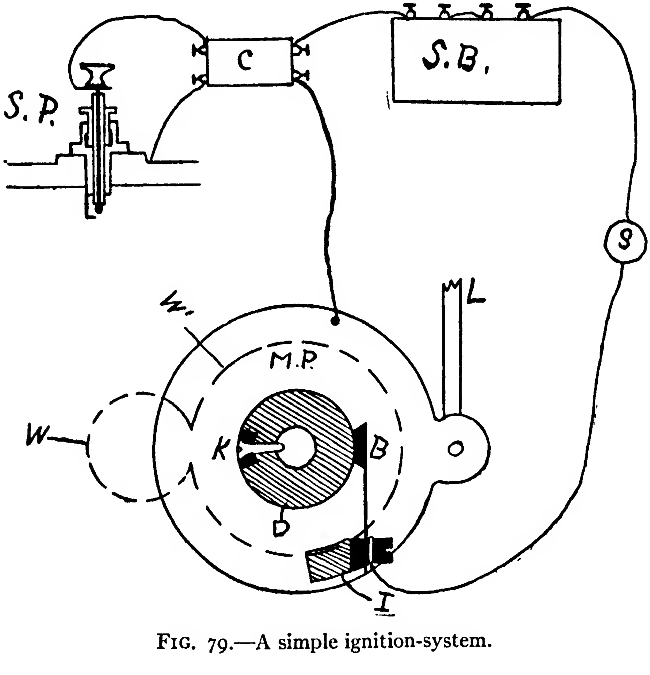


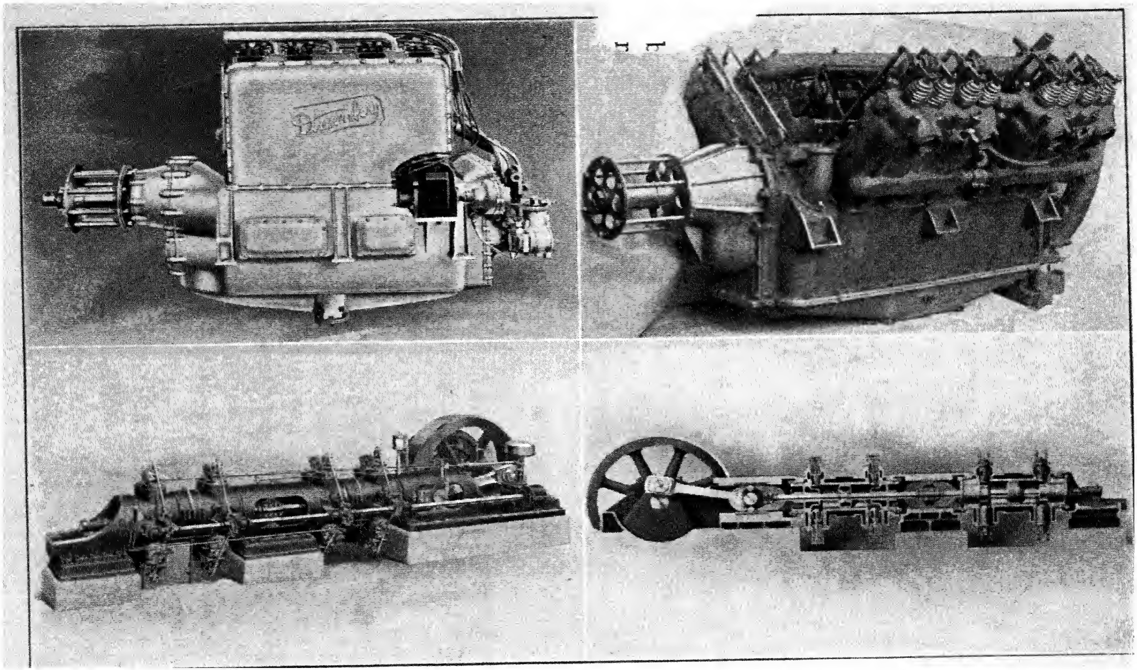
FIG. 79.—A simple ignition-system.

ries a metallic block B held against the disk by means of a spring. Now as the cam shaft revolves the contact K and the block B will be brought together thus completing the circuit through the switch S, the storage batteries S. B. and the primary of the induction coil C. This will induce a high electromotive force in the secondary of the induction coil, the terminals of which go to the insulated rod in the

spark plug and the cylinder of the engine. As the contact K moves by the block and the circuit is broken, a spark leaps across the gap inside the cylinder and the mixture is fired. The spring and block B are insulated at I from the movable plate and therefore the circuit can be made only when K and B are in contact. Since this happens only once during each two revolutions of the main shaft there will be but one spark during this time, as the four-cycle engine requires. The position of the block B may be adjusted by moving the lever L and, therefore, the spark may be timed to the exact instant of maximum compression.

A magneto is frequently substituted for the storage batteries. A magneto is a small generator employing permanent field magnets instead of electromagnets and belted to the main shaft of the engine. If this is substituted for the batteries whenever the contact is made at B a current will flow through the induction coil and a spark will result as before.

In the magneto system proper, however, a high tension generator is employed and both the storage batteries and induction coil are dispensed with. The armature of a high tension magneto has two windings, a primary of coarse wire and a secondary of fine wire just as an induction coil has. The terminals of the primary winding are connected with the block B and the movable plate just as before, while the secondary winding is connected through a condenser with the spark plug. As the current in the primary is made and broken at B the high electromotive force induced in the secondary charges the condenser and this immediately discharges across the terminals of the spark plug and ignites the mixture. When the engine has more than one cylinder in addition to the timing device for producing a spark at the instant of maximum compression in each cylinder,



Duesenberg and Sturtevant aëroplane engines and double-acting tandem gas engine for large power purposes.

there must also be placed in the secondary circuit a *distributor* to throw the spark to the proper cylinder.

Gas Engine Development.—In early gas engine construction it was sought to secure increased power by increasing the size of the cylinder, but it was soon found that this could be accomplished to much better advantage by employing several cylinders instead of one. Very soon the four-cylinder engine came into general use and now we have engines with six, eight and twelve cylinders. By increasing the number of cylinders the number of explosions per revolution is increased and therefore the impulses acting upon the crank shaft are more frequent. In a four-cylinder engine there are four explosions and resultant impulses for every two revolutions, or one explosion for each half revolution. A more uniform development of power results. There is less vibration. Lighter flywheels and lighter construction throughout can be employed.

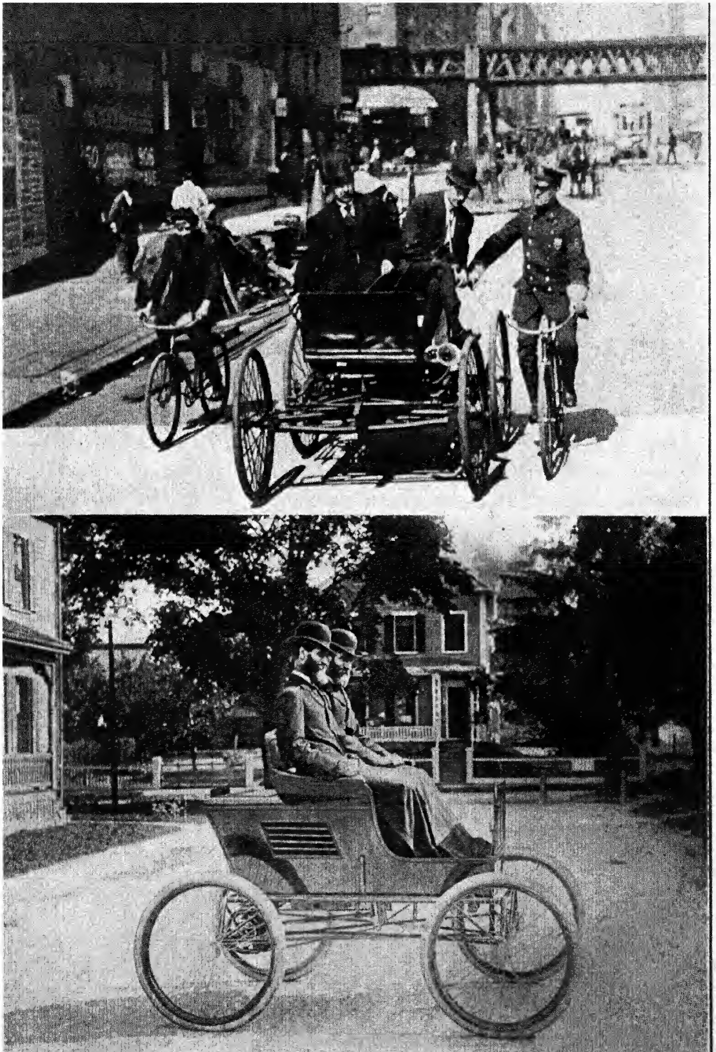
The wonderful development of the aëroplane has been dependent upon the construction of light-weight high-power engines and one of the greatest recent achievements has been in this direction. A recent Duesenberg model weighs about 3½ pounds per horse power and one of the new aëroplane motors of the B. F. Sturtevant Company develops one horse power for each 2.3 pounds of weight. The famous French Gnome engine and the similar Gyro engine made in this country are light powerful engines of the rotating cylinder type with which many of the altitude and speed records have been made. The Gyro engine develops 110 horse power and weighs but 270 pounds. The new Liberty motors develop over 400 horse power and the bombing planes which the Handley Page Company proposes to build and fly across the Atlantic are equipped with two of these motors. The new type of Zeppelin carries six 250-

horse power motors. The carburetors of aëroplane engines are now equipped with an automatic compensating device which prevents a change in the quality of the mixture with varying altitudes.

One of the greatest present needs of the petrol motor is a carburetor that will make possible the use of heavier oils. Very marked advancement has been made in this direction and a grade of gasoline is of necessity used now that would have been impossible a few years ago. But if kerosene, benzol and alcohol are to come into general use still further improvment must be made and there is no doubt but that it will be.

One very important application of the gas engine as distinguished from the gasoline, or petrol, motor has been in the natural gas fields and in connection with producer-gas plants. The gas engine has adapted itself to large power purposes and where natural gas is available it has given very cheap power. It has been found, too, in many instances that it is cleaner, more economical and more efficient to convert the carbon of coal into producer gas and burn it in a gas engine than it is to burn the coal under a steam boiler and employ a steam engine.

The Automobile.—The most fitting symbol of the Twentieth Century spirit is locomotion. For forty years steam and electric locomotives, bicycles, motor cars, airships, aëroplanes and submarines have been following each other with almost bewildering rapidity. Transportation has expanded to embrace not only the surface of the earth but the heavens above and the depths below. The conquest of time and space has become a passion with the race. These natural barriers, suffering assault after assault, are dwindling to the vanishing point. Every day this planet grows smaller. Isolation is disappearing and in this freer



The Haynes automobile on the streets of Chicago in 1895 and the first Stanley Steamer.

intercourse of men and nations lies the future hope of world peace.

To this rapid extension of the means of travel nothing has contributed more than the motor car. This application of the gasoline engine has spelled transportation for the common man. It has promoted travel, stimulated business, made the nation more efficient, simplified recreation and as Dr. Frank Crane says, "made life richer, freer and happier."

The first four-wheeled vehicle to be propelled by a gasoline motor was made in France by Messrs. Pannard and Levassor in 1889 and with marvelous rapidity the motor age was ushered in. Seldom has the adaptation of a great invention made so universal a conquest in so short a time.

In this country, George B. Selden in 1879 applied for a patent to cover the use of the gas engine in road vehicles, but the patent was not issued until 1895. In the meantime Elwood Haynes of Kokomo, Indiana, had been experimenting along similar lines and in 1893 built America's first successful automobile. The first actual run of the car was made in Kokomo, July 4, 1894. The car driven by an engine that weighed 180 pounds and developed one horse power made the "exceptional" speed of 6½ miles an hour and covered 28 miles on a gallon of 8 cent gasoline. This car is now on exhibition in the Smithsonian Institution. The brothers F. E. and F. O. Stanley in 1897 built a steam car which in the following year and again in 1906 established new speed records. In many respects steam is the ideal power for the automobile and the Stanley steamers are still widely used.

A few facts will show the wonderful growth of the automobile industry. The first automobile was sold in the

United States in 1896—22 years ago. To-day there is one automobile for every 24 of the population or one to every fifth family. The automobile business is the third largest industry in the country and employs 5 per cent of the whole population. There are $736,000,000 of capital invested in the industry, and the annual volume of business is nearly a billion dollars. There are 4,000,000 passenger cars in the country covering 60,000,000,000 passenger miles per year which service at 2 cents per mile would cost $1,200,000,000. The passenger mileage of the automobiles of the country is greater than that of all the steam and electric roads combined. And yet the automobile is not a competitor of railroads and traction lines. It has developed an independent traffic, hitherto non-existent, and is their greatest feeder. Taxed to their utmost and more, the railroads would be overwhelmed without the motor car.

The automobile and the tractor have revolutionized farm practice. Market and farm have been brought together. Time and energy have been saved. The man power engaged in agriculture has been multiplied and the labor problem largely solved. Horses on the farm are becoming obsolete and like the sickle and the flail will soon be relics of the past. The 35,000,000 bushels of food which they eat per year will help to feed the starving populations of the earth. Fifty thousand farm tractors were in use in this country at the beginning of 1917 and as many more were built in that year. What the country needs is a cheap tractor and the genius of a Henry Ford applied to its manufacture and distribution. A tractor for $250 would enable this country to feed the world.

The army motor truck and the military tractor are the motive power of a modern army. In the spring of 1914, just before the Great War, Germany mobilized the motor

cars of the Empire for the treacherous attack on the peace of the world which she had so foully planned. She had the Allies at a tremendous disadvantage and it was only by pressing into service every motor car, truck and taxicab found on the streets of Paris that Joffre was able to support his army at the Marne. Transportation facilities are indispensable to successful field operations. An army can advance no faster than its artillery can be moved forward. During the first four years of the war the artillery tractors have been able to travel barely three miles an hour, but the United States has produced a giant tractor that will double the speed and that, too, over the roughest shell-torn battle field. Fallen trees and deep holes are no obstacle to its progress.

The motor car service and strategic railroads of Germany were of the greatest assistance in her early successes. But the Allies were quick to motorize their armies. At Verdun, when the German artillery had destroyed the railroad communications, the motor trucks took their place, and without this aid the glorious resistance of the men who said, "they shall not pass" would have been impossible. The rebuilding of roads and bridges waits upon motor truck transportation of supplies. Rapid motor transport of the wounded from the battle front saves many lives to the army and the home. The transport of troops from front to front multiplies the efficiency of the reserves. The motor requirements of the United States Army in France for 1918 are 100,000 trucks which including repairs will cost $400,000,000. The cost of the war is prodigious, but the liberties of the earth are worth its last resource.

Thus in peace and war the wonderfully efficient, light but powerful gasoline motor has made a record for service unmatched by any other invention of modern times.

A GAS EXPLOSION

Borrow a large Woulf bottle from the high school laboratory or procure a gallon can and cut another hole in the top. Fit the necks of the bottle or the holes in the can with

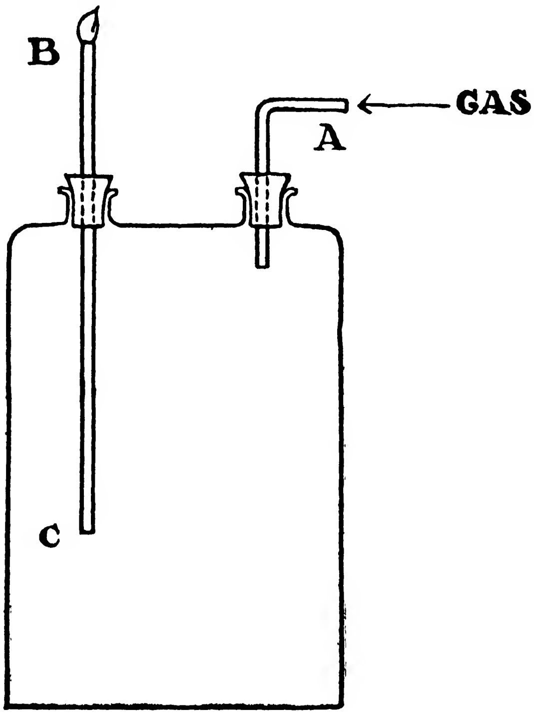


Fig. 80.

one-holed stoppers carrying glass tubes as shown in the diagram. The tube BC should be of fairly large diameter. Connect the bent tube A with a gas cock by means of rubber tubing and turning on the gas drive out the air from the

bottle. Light the gas at B and then withdraw tube A with its stopper, at the same time turning off the gas, but do not stop the flow of gas until the stopper has been partially removed. The gas will continue to burn at B with a small flame for some time and then seem to disappear entirely. Do not conclude that the experiment is a failure but wait and suddenly a very sharp report will occur and the bottle will be filled with a sheet of flame. If done at night or in a darkened room the effect is heightened.

As the gas escapes and burns at B, air enters through the open neck until the bottle is full of an explosive mixture of gas and air, when the feeble flame at B will strike down into the mixture producing the explosion. This is the same as the "striking back" of a hot plate or gas stove, and aside from the fact that there is no compression it is the same as the explosion in the cylinder of a gas engine.

Chapter XIII

A CENTURY OF AGRICULTURAL PROGRESS

Difficult as it may seem for many of us to believe, the greatest problem of all nations has been to make this old earth yield enough of food stuffs to satisfy the hunger of the many millions that inhabit it. Especially has this been true during the Great War and most keenly have people everywhere been brought to realize it. Yet until comparatively recently the genius of the race has not been directed toward improving methods of agriculture. Labor-saving devices for multiplying the man power and efficiency of the artisan and mechanic began to appear, but the farmer plodded on in the primitive ways of his fathers. McMaster, in his "History of the People of the United States," says, "The Massachusetts farmer who witnessed the revolution plowed his land with a wooden bull plow, sowed his grain broadcast, and, when it was ripe cut it with a scythe and threshed it out on his floor with a flail." Each householder was almost entirely self-sustaining, producing nearly all that he and his family required. He sold but little and bought less. There was no need for producing more, and a virgin soil and large crops did not stimulate inventive genius along agricultural lines. But with the building of cities, the growth of manufacturing and the great divisions of labor it became imperative that the farmer should provide food, not only for his own family, but for the ever increasing army of those not engaged in agriculture. To do this brought profits, and the incentive of private gain encouraged

efforts toward increased productiveness and the development of new devices and better methods.

No more interesting chapter in agricultural growth can be found than that which tells the story of harvesting machinery. From the ancient Eygptians down to the beginning of the last century the reaping hook, or sickle, was the sole means of cutting grain. These early implements were made of flint and bronze. Pictures upon the tombs at Thebes show slaves using these crude tools. Later iron and steel came into use, but not until the last century was any substantial progress made in improving harvesting machinery.

The scythe, still a familiar tool on all farms, was the first development from the sickle. It differs from it in that it enabled the operator to use both hands instead of one. A clumsy, heavy instrument at first, the blade of the scythe was gradually made lighter, the handle lengthened, and fingers were added to collect the grain and carry it to the end of the stroke, so that it might be laid in a swath for drying and made ready for the binder. This tool is distinctly an American development and was given the name cradle. It was introduced during the last quarter of the eighteenth century and very rapidly spread to all countries. No other hand tool has been devised that equals it for the harvesting of grain. Whereas with the sickle it required seven men to cut, bind and shock two acres of grain per day the use of the cradle enabled two men to do the same amount. Its use, too, has not yet passed, for there are places where the land will not permit of the use of reapers and the cradle is the only practicable instrument.

The first practical efforts toward harvesting wholly by mechanical means began about the year 1800. Some attempts in this direction had been made by the Gauls and

Romans nearly two thousand years before but nothing of permanent value resulted. Just preceding and following the year 1800 a number of patents were granted in England to inventors of reaping machines. But all of these were unsuccessful, for as late as 1851 at the World's Fair in London the United Kingdom was unable to exhibit a reaping machine. For the solution of the harvesting problem the world turned to America, but up to 1831 no practical, working reaper had been developed. In that year came the McCormick. It was the first successful machine ever used, and, although crude at first, it was rapidly improved. Built in an old blacksmith shop near Steele's Tavern, Virginia, early in the fall of 1831 Cyrus McCormick hitched four horses to his machine and drove into a field of oats on the farm of John Steele. Great interest marked the event and a large company of neighbors witnessed the performance. This was the first grain ever cut by machinery. In less than half a day, to the amazement of everyone, six acres had been reaped, or as much as six men would have done in a whole day by the old-fashioned method. The introduction of the reaper markes a turning point in agricultural progress. Nothing of similar importance in this field had occurred in more than two thousand years. Like all other labor-saving machines it increased production and decreased its cost, giving the world a tremendous start toward cheaper bread.

Strange as it may seem, ten years passed before McCormick was able to make his first sale. Two years later twenty more were sold and in 1844 fifty. He continued to improve his machine and in 1845 went to Chicago where in 1847 he built a factory and started the world's greatest reaper works.

The first machine had a platform for receiving the grain,

a knife for cutting it and a reel to gather it. The driver rode one of the horses while another man walked beside the machine and raked off the grain. A little later a seat was added for the raker and then an automatic rake, another labor-saving device.

From 1857 to 1870 a number of other men, among them W. H. Kirby, D. M. Osborne, and William N. Whitely secured patents on improved reapers and formed companies for their manufacture. But up to this time no one had been able to devise a successful binder for the reaper. The grain was cut and raked off, or "dropped" in bundles, after which it had to be bound by hand. The first attempt at solving this problem was made by two farmer boys of DeKalb, Illinois, the Marsh brothers. They devised means to lift the grain to a table where two men, who rode on the machine, bound the bundles and dropped them to the ground. Up to 1879 about 100,000 machines of this type had been built and sold.

The next development was the self-binder. Many inventors worked upon the problem and, necessity being so great, its solution was not long delayed. In 1865 S. D. Locke secured a patent which was developed into the Withington wire binder and was first manufactured by McCormick in 1875. The device consisted of two steel fingers that moved back and forth and twisted a wire band about each bundle of grain.

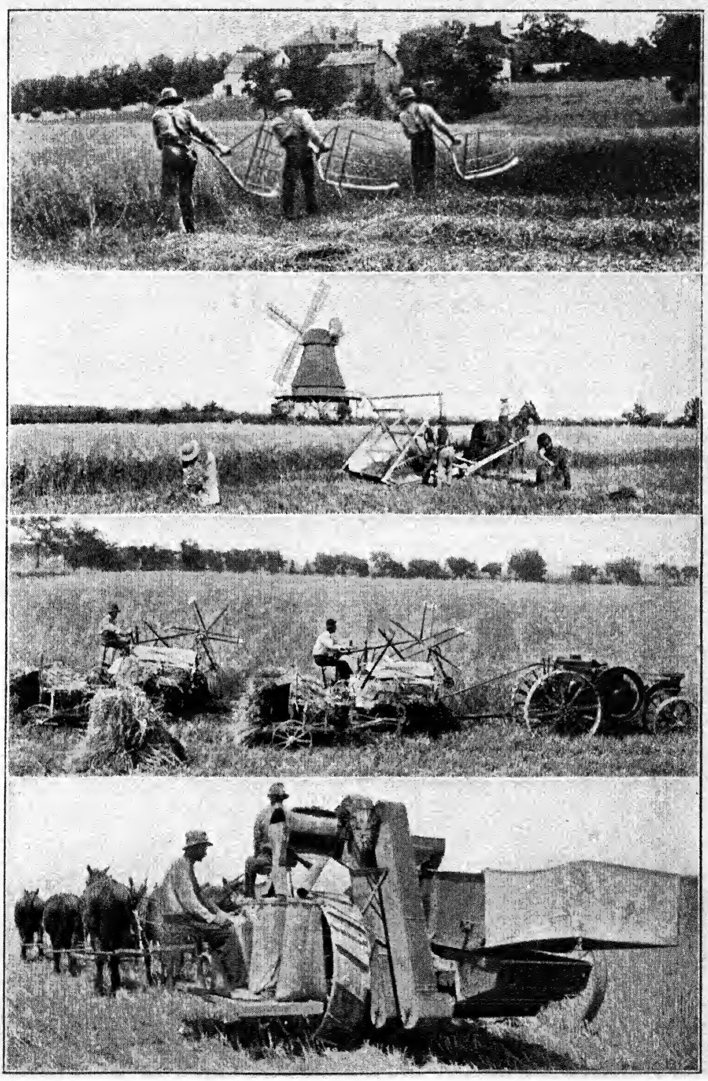
The wire binder, however, was not popular with the farmers and in 1878 John F. Appleby perfected a twine binder attachment. Its steel arms would pass a cord about a sheaf of grain, tie a knot, cut the cord and throw off the bundle. Here at last was what the world needed. The mechanism worked perfectly and was quickly adopted by the leading manufacturers of harvesting machinery. The

necessity for cheap twine was met through the enterprise of William Deering, a prominent manufacturer of twine binders. He persuaded Edwin H. Filter of Philadelphia, one of the largest twine manufacturers in this country, to make a single strand binder twine.

The reaper as thus developed is the reaper of to-day. Improvements designed to make the machine mere durable and reliable, lighter to draw and requiring fewer field laborers have been added. One of the latest improvements is the hitching device which makes possible the hauling of two or more binders by a single tractor. Control devices enable the man who sits on the binder seat to operate the tractor. Attachments have also been added for placing the grain in shocks, thus doing away with the necessity of having men follow the machine in the field.

Two outgrowths of the binder are the header and the harvester-thresher. In the modern header the horses push the machine from behind and the cutting knives in front of the wheels drop the grain on to an endless conveyer which elevates it to a wagon drawn beside the machine. Only the heads and upper portion of the stalks are cut. The cutting widths are 10, 12 and 14 feet.

In the early days and even now in some parts of the world threshing was accomplished by pounding out the grain from the straw by means of a club called a flail. In China oxen are driven over the straw placed on a hard floor and the tread of their feet separates the grain. When the farmer was required to produce no more than was sufficient for his own needs such primitive methods passed as satisfactory. But with an ever increasing demand for bread and with improved methods of cultivation and reaping a more rapid means of separating the grain became a necessity. And the race has always had a way of solving



From the hand cradle to the harvester-reaper and thresher.

such problems. In this case the answer was the modern thresher, or grain separator, run by a steam or gasoline engine and capable of threshing out more than one thousand bushels of wheat per day. And then for the big wheat farms of the West came the combined harvester-thresher drawn in some cases by from twenty to thirty horses or mules and in others by several powerful tractors. A single one of these machines and four men will reap, thresh and bag from two to three thousand bushels of wheat in a day.

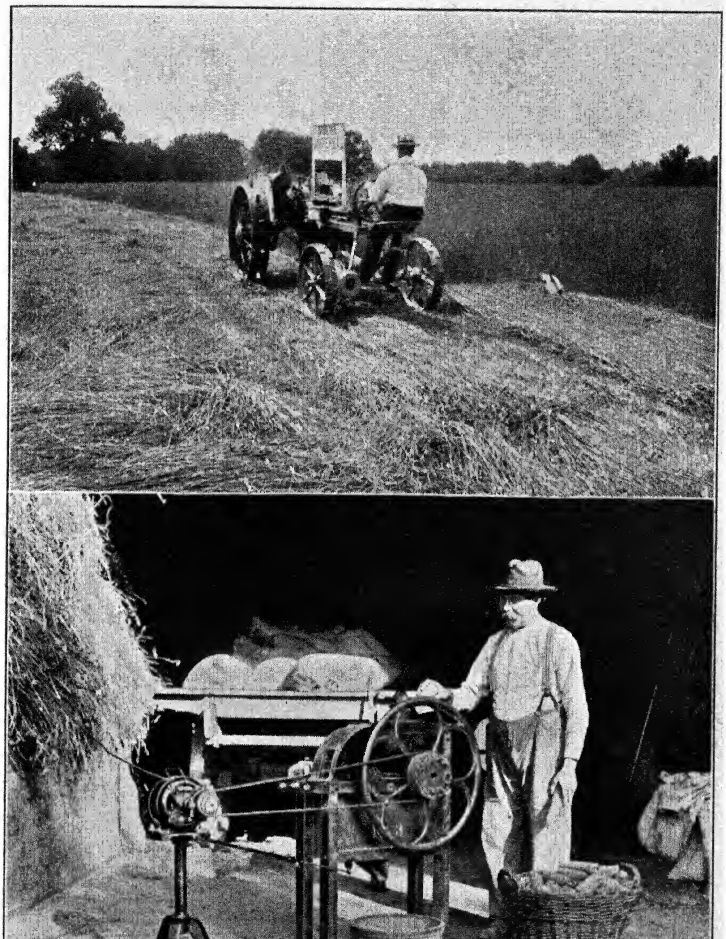
Thus in little more than half a century the methods of harvesting were entirely revolutionized and more progress made than in all the centuries that had preceded. When we consider that agriculture is the basic industry without which the race would starve, we see the immense significance of all this. Anything which increases the output of the soil lessens the world's hunger and makes possible the present highly organized state of society and industry by which so large a percentage of the people must be fed through the efforts of a comparatively few. According to the census of 1910 there were engaged in agriculture in the United States 32½ per cent of the population or, in other words, about one-third of the population feed the whole. And not only this but they produce large quantities of food stuffs in excess of our own needs foı export to foreign nations.

But it is not alone in the harvesting industry that agricultural progress has been made. From the wooden bull plow and small acreage of the revolutionary days to the large tractor-drawn gang plows and vast fields of the middle West we pass over a period of marvelous expansion. A century ago and less all farm work was done by hand. Cultivating, planting, mowing, haying, harvesting—all were accomplished by man power. But for all this work

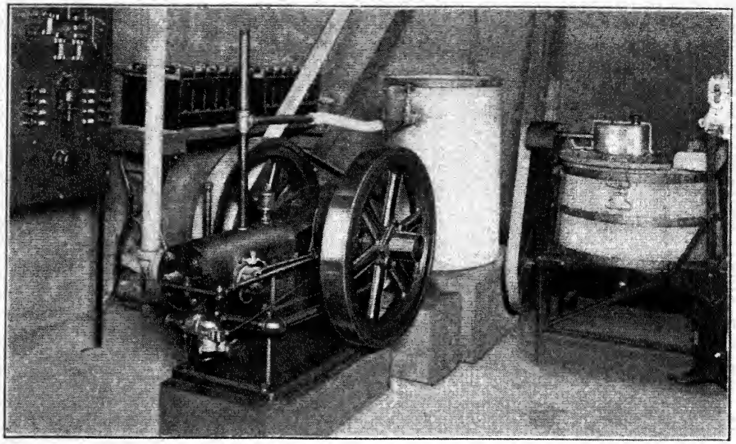
machinery was gradually evolved. For many years the faithful horse was harnessed to the operation of it, but now the gasoline and steam tractors are taking his place. A single tractor, operated by one man does the work of seven horses. With it he will plow as high as twelve acres in a day or cultivate from sixteen to twenty acres. Tractor-drawn seed drills, planters, cultivators, mowing machines and harvesters have multiplied many times the man power engaged in agriculture and are affording the best solution of the farm labor problem. By increasing the output of our farms and at the same time decreasing the cost for labor this application of the universal gasoline engine to farm needs is of tremendous importance. A modern tractor is as powerful as five horses, as enduring as seven, costs less than four horses, requires less care than one horse, occupies less room than one horse and eats only when it works.

In the dairy branch of the agricultural industry to take the place of hand milking has come the power-driven milking machine, a single machine operating upon two cows at once and doing the work with much greater rapidity and thoroughness. The old-fashioned method of setting the milk in pans and waiting for the cream to rise, followed by hand skimming, has been almost entirely displaced by the cream separator which, either hand or motor driven, does in a few minutes work that formerly required from twelve to fifteen hours and with greater efficiency.

Modern inventions have completely revolutionized farm practice, and nothing has contributed more to increase its efficiency and to brighten the lives of those engaged in this most useful of all industries than the modern electric power and light plant. The farm to-day may have all the conveniencies of the city with the glorious freedom of a life



The farm tractor and the portable electric motor.



An Edison electric power and light plant for farm and domestic use.

in the open. Light, air, power make a combination irresistible in the promotion of happiness and prosperity. But back of it all stand the gasoline engine, the dynamo, the storage cell, the motor and the electric light, inventions that have been made in the last forty years. The gasoline engine drives the dynamo which generates current to charge the cells, and then this wonderful energy can be wired to any part of the house or outbuildings where it may be had by the pressing of a button or the throwing of a switch. It is thrown on or off at a moment's notice and is used only as need requires. The accompanying photographs show its many applications. It lightens the work of the housewife, adds comfort to the home, keeps the boys and girls contented on the farm and is a tremendous factor in dispelling the gloom and drudgery of farm life.

And then there is the automobile, that marvelous combination of luxury and utility, which has done more to hitch the farmer's "wagon to a star" than any other single invention. As Dr. Frank Crane says, "The automobile has made life richer, freer and happier." But for no one more than the farmer. It has widened his horizon, added to his prosperity and multiplied his means of recreation.

But we must not forget the telephone and free rural mail service which have been such tremendous factors in banishing the farmer's isolation. The daily paper and the abundance of agricultural and other literature which come to his household have educated him not only socially and politically but professionally as well, for farming is now a profession. It has ceased to afford a calling to anyone who can do nothing else. It is a science, an industry reborn through the brains and inventive genius of America.

EXPERIMENTS

1. *Testing for Acids.*—Place strips of blue and red litmus paper into vinegar, lemon juice, orange juice and solutions of alum and cream of tartar. To obtain a solution place a little of the substance to be dissolved in a test tube or small dish and cover well with water. Shake vigorously and warm if necessary to hasten the process.

In each of these cases the blue litmus will turn red and the red litmus will be unaffected. This is the test for an acid and many more substances may be tested in a similar manner.

2. *Testing for Alkalies.*—Make similar tests with solutions of soap, baking soda, washing soda, lye and borax. These substances turn red litmus blue. This is the test for an alkali, or a base, as it is called in chemistry.

3. *Acid and Alkaline Soils.*—Moisten samples of various kinds of soils and bring in contact with them pieces of red and blue litmus paper. Be sure the paper is pressed well against the soil and allow it to remain so for several minutes. Then remove it and examine for any change of color. The soil may show the presence of either acid or base and, perhaps, it is neutral showing no color change at all.

Old soils are acid and in order to grow good crops this condition must be corrected. Particularly is this true for leguminous plants such as beans, clover and alfalfa.

4. *Correcting Soil Acidity.*—Take a basin full of acid soil and add to it 15 to 25 grams of burned lime. Stir the mixture thoroughly and moisten with water. Now test for acidity and if the soil is still acid continue to add lime followed by thorough mixing until the blue litmus will not turn red and red litmus will just barely turn blue. The soil has now been "sweetened" as the farmer says.

Many tons of lime are used each year to destroy the acid condition of old soils.

Repeat the above experiment, substituting wood ashes for lime. Not only will wood ashes correct the acid condition but they give to the soil the element potassium, one of the three essential constituents of commercial fertilizers.

To show the alkaline character of wood ashes shake some with water and allow the sediment to settle. Test the clear liquid with red and blue litmus paper. This is a weak solution of lye, and strong lye was formerly used on the farm to heat with fat scraps in the making of soft soap.

5. *Testing the Quality of Lime.*—Place about 40 or 50 grams of burned lime in a small basin and moisten it well with water. Warm the mixture a very little. If the lime is fresh the mass will expand and get hot, giving off steam. This process is called slaking, and fresh lime slakes readily. Place some of the slaked lime in a bottle and fill half full of water. Shake thoroughly and allow the mixture to stand for several hours. Pour off the clear liquid and blow into it through a glass tube or straw. The carbon dioxide in your breath will turn it white because of the slaked lime dissolved in the water. If this does not happen, then the lime did not slake well.

Place a very little of the lime in a test tube, add 10 cubic centimeters of water and then hydrochloric acid, a few drops at a time as long as the lime continues to dissolve. If the lime is of high purity, there will be but very little insoluble residue.

6. *Nitrogen in Soil.*—Mix a little soil with an equal bulk of soda-lime and place the mixture in a test tube. Fit the test tube with a one-holed stopper and a bent delivery tube dipping beneath the surface of water in another

test tube. Heat the mixture in a Bunsen flame 5 to 10 minutes and test the water with red litmus paper. If it turns blue, nitrogen is present, the nitrogen having formed ammonia and dissolved in the water.

7. *Nitrogen in Organic Compounds.*—Mix a small quantity of dry clover, peas or meat with soda-lime and repeat the above experiment. The test will show ammonia.

8. *To Detect Renovated Butter and Olemargarine.*—Melt a little of the sample in an iron spoon. Pure butter will melt quietly and produce much foam. Renovated butter and oleomargarine bump and sputter and will produce but little foam.

9. *To Test for Formaldehyde in Milk.*—In the bottom of a test tube place a half-inch layer of concentrated sulphuric acid and add one drop of a dilute solution of ferric cholride. Now incline the test tube and pour down the side some of the milk to be tested. If formaldehyde is present at the juncture of the two layers a purplish ring will be formed.

To show the delicacy of this test add one drop of a 5 per cent solution of formaldehyde to a pint of milk, stir well and make the test.

10. *Hard and Soft Water.*—Make a soap solution by dissolving 2 grams of castile soap shavings in 250 cubic centimeters of denatured alcohol. Then add 60 cubic centimeters of water; if the solution is not clear, filter by means of a folded filter paper and funnel. Preserve in a tightly stoppered bottle.

Now to a test tube two-thirds full of water add a few drops of the soap solution and shake. If a cloudiness occurs and soapsuds do not form at once the water is hard. Continue to add the solution, a few drops at a time, with shaking until permanent suds form. The degree of hardness

may be judged by the quantity of soap solution that must be used to soften the water.

Repeat, using distilled water or rain water. The precipitate that forms with soap in hard water is insoluble lime soap and until all the lime has been precipitated the cleansing action of the soap cannot become effective.

CHAPTER XIV

TWO CENTURIES OF ELECTRICITY

For two centuries the word electricity has carried with it more of fascination and mystery than any other word in the language. So intangible and elusive, so subtle and immaterial, and yet so powerful and far-reaching in its effects, electricity like gravitation must be accepted but cannot be explained. Unable to understand its origin and nature, it is nevertheless possible to determine the laws that govern it and to harness this remarkable manifestation of energy to the performance of the world's work. Each decade has seen our knowledge of it broaden and its uses multiply. So marvelous and varied have been its applications that to the popular mind nothing seems too wonderful for belief, if only the word "electrical" can be given in explanation. In recent years one triumph has followed another in such rapid succession that electricity has seemed at last to furnish the long sought key to the realm of magic. It lights our streets and homes, rings our door bells, runs our street cars, operates the machinery of our factories, sends our messages both by wire and ether, liberates the metals from the minerals of the earth, produces the hottest form of furnace, picks up tons of iron and steel, produces the X-ray and performs a multitude of household tasks that have made life richer and happier and this world a better place in which to live.

It was in 1681 that Otto von Guericke invented the first electrical machine for producing electricity by friction and

a little later Stephen Gray in England made the important discovery that certain substances are conductors and others insulators. Almost at the same time Cisternay Du Fay of France discovered that electric charges are of two kinds which he called "vitreous" and "resinous" but which Franklin later designated as "positive" and negative." These discoveries and others which followed aroused great popular interest and numerous experimenters were set to work. Demonstrations with the new found "virtue" became the order of the day. With powerful friction machines heavy charges were developed and great spectacular displays were made. At a lecture before the Academy of Sciences in Berlin in 1744 one demonstrator succeeded in igniting ether by means of an electric spark, and a little later gunpowder was exploded in a similar manner. On one occasion at a dinner party given by Bose, the host insulated the legs of the table by placing them on pieces of pitch and connected the table with an electrical machine concealed in another room. As his guests were about to be seated, at a signal from Bose, the machine was started and to the amazement of the party "flames of fire shot from flowers, dishes and viands giving a most startling but beautiful display." To add to the brilliant electrical effects the host introduced a very charming young woman, also insulated from the floor and mysteriously connected with the electrical machine. As each guest touched her finger tips, he received a shock that "made him reel." Demonstrators and the public alike were alive with excitement. The world seemed on the verge of a new era and indeed it was. Up to that time, however, electricity had been little more than a plaything. No practical use had been made of it nor was there destined to be for nearly a century.

The next great discovery showed that electric charges

could be stored. It was made by the Dutchman, Pieter Van Musschenbroeck and a German Von Kleist, working independently of each other. Pieter Van Musschenbroeck was a famous teacher of Leyden and the modern condenser taking its name from the ancient Dutch town was perfected by him and given to the public. The invention gave a new impetus to electrical pursuits and added much to the experimental possibilities of the subject.

The story of Franklin and his kite is too well known to need repeating here but just to keep the record straight let us note that this bold scientist at the risk of his life drew the lightning from the thunder clouds and proved its identity with the electricity of the Leyden jar. By connecting the key at the end of his kite string with the knob of the jar he could charge the jar as readily as with the electric machine.

Experiments

1.—Rub a warm, dry glass rod with a piece of silk and hold it over bits of paper, cork filings, pith balls, etc. Do the same, substituting for the glass rod a stick of sealing wax, a hard rubber comb or a rod of ebony and for the silk a piece of flannel.

2.—Make a wire stirup. Suspend it by a silk thread from a hook and place in the stirup the electrified glass rod. Now bring near one end of the rod an electrified rod of sealing wax or a rubber comb. Note that the two rods attract each other and that the suspended glass rod will follow the other about a circle.

Electrify another glass rod and bring it near one end of the suspended rod. This time, however, the rods repel each other.

Repeat the above experiments placing an electrified rod of sealing wax in the stirup and presenting to it, first an electrified glass rod and then an electrified rod of sealing wax.

From these experiments it will be seen that like kinds of electrification repel each other and unlike kinds attract. The charge on the glass rod is called positive and that on the sealing wax negative.

3.—Make a *pith-ball electroscope* by bending a piece of heavy wire so as to make a hook at the top and insert the bottom in a large cork stopper to serve as base. By means of a silk thread suspend a pith ball from the hook. Now bring an electrified rod near the pith ball and it will be attracted to the rod, remaining in contact for a moment and then flying away. Do your best and for several moments you cannot bring the rod and pith ball in contact. The latter will resist all your efforts and fly about in a most baffling manner. Explain.

The pith for such experiments may be obtained from young elder shoots and when dry is easily carved with a sharp knife into any shape.

4.—On a cold winter's evening warm a sheet of paper before the fire and then rub it briskly for a few moments with your coat-sleeve or a piece of fur. Now place it against the wall and it will adhere for several seconds.

5.—Also on a similar winter's evening try this experiment. Rub your hands briskly together and then with one finger extended touch lightly the fur of the house cat as she reclines on the rug before the fire. You will observe the fur start and the cat give a twitch as though she had received a shock. A small electric spark leaps between your finger and the cat.

On a frosty night in an unlighted room briskly stroke the

back of a cat and an electrical display accompanied by crackling sparks will follow.

6.—In the winter when the air is crisp and dry shuffle the feet briskly over a wool rug for a few seconds and then present one finger to a lamp fixture, a gas pipe or a radiator when a spark will leap across the gap. A gas jet may even be lighted in this way.

7.—A very simple electric machine called an *electrophorus* may easily be made and with it a good sized electric spark obtained. Buy a couple of pie tins about ten inches in diameter and pour into one of them a melted mixture of equal parts of brown resin and gum shellac. Or the resin and shellac may be placed directly in the tin and melted and mixed over a small fire. Allow the mixture to cool. Then warm the end of a short stick of sealing wax and press it firmly against the center of the other tin. This makes an insulating handle. The outfit is completed by providing a square of flannel with which to rub the mixture of resin and shellac.

To work the electrophorus, rub the mixture briskly and then having warmed the cover tin take it by the handle and place it on the mixture but do not let any part of the metal of the two tins come in contact. Now touch the surface of the cover tin with the finger. Then, *first* removing your finger lift the tin with the insulating handle and present it to the end of your nose or the knuckle of your other hand when a spark will jump between the two and you will experience a slight shock.

In this case the upper tin has been charged by induction. The mixture in the bottom tin has a negative charge generated on it by rubbing with the flannel. When the cover tin is placed upon this, touching the mixture at only a few points of contact, positive electricity is held bound on the

under side of the tin and negative electricity is repelled to the upper side. Now when the finger is placed on the cover tin the negative charge is repelled into the body of the experimenter but the positive charge is held on the tin and when removed distributes itself over the surface.

This principle of induction is the basis of one very important type of static machine.

8.—The construction of the *Leyden Jar is* described under wireless telegraphy and we will simply add here that a fruit jar may be used for the glass insulator and a large flat cork for the top. The tinfoil coatings may be made to adhere to the glass with shellac. A brass rod passing through the cork and carrying a brass chain or copper wire reaching to the inner tinfoil will serve for knob and connector.

Now a Leyden jar may be charged by holding the jar in the hand or connecting the inner tinfoil with the earth and repeatedly bringing in contact with the knob the charged disk of an electrophorus.

To discharge the jar, bend a piece of wire in the form of a half circle and to the middle of it attach a small piece of glass tubing for an insulating handle. Then placing one end of the wire in contact with the outer coating of the jar bring the other end near to the knob and a brilliant spark will jump across the gap. This is the same sort of a discharge that produces wireless waves, and in wireless telegraphy the Leyden jar has important uses.

9.—By means of the discharger pass a spark from a charged Leyden jar through a gas jet and the gas will be ignited.

10.—In a darkened room hold a charged Leyden jar in one hand and with the other bring near to the knob an incandescent lamp bulb. A brilliant glow will fill the bulb

as the discharge passes through the highly rarefied gas that it contains.

11.—A frictional static machine like that shown in Fig. 81 may be made as follows: Secure a board 2 feet long and 9 inches wide for a base. At the glazier's get a glass disk

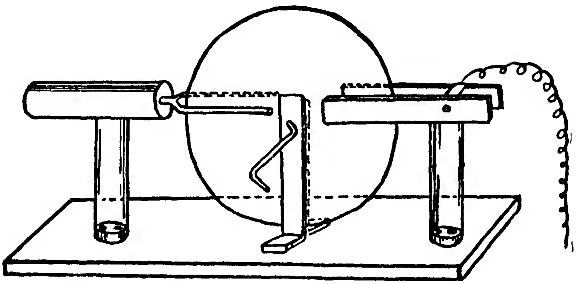


FIG. 81.—A static machine.

about 12 inches in diameter and have a quarter-inch hole ground in the center. Between two uprights, mount the disk on a brass rod bent at one end to provide a handle. At one end of the wooden base fasten a good sized cork and over this fit a piece of large glass tubing or a lamp chimney. To the top of the chimney fasten a rubbing attachment made of two sticks of wood covered with silk. The frictional qualities may be improved by rubbing lard on the silk and then coating it with an amalgam made by dissolving a little zinc dust and metallic tin in a cubic centimeter of mercury. At the opposite side of the disk mount in similar manner a wooden cylinder covered with tinfoil and carrying in one end a metallic fork made of heavy wire and having small pointed projections fastened to each prong. For these projections short pieces of wire may be sharpened at one end and the other wound about the prong.

The silk rubbing device should be connected by a wire to a gas or water pipe or some other ground.

As the machine is operated the glass disk becomes positively charged and the pointed combs on the prongs of the fork take off the charge which is repelled to the opposite end of the tinfoil-covered cylinder. A Leyden jar may be quickly charged by connecting the knob with this cylinder and numerous experiments with static electricity performed.

FURTHER DEVELOPMENTS IN ELECTRICITY

For half a century after the invention of the Leyden jar no new electrical discovery was made and then came Galvani and Volta, pioneers in the field of current electricity. Up to this time the continuous flow of an electric current along a metallic conductor was unknown. Static electricity is essentially electricity at rest with momentary discharges of great brilliancy, but the production of a constant difference of potential and a uniform flow of current was impossible.

In 1791 Luigi Galvani, an Italian physician, was experimenting with static electricity to learn its effects on the nerves and muscles of the body. Using a dissected frog for the experiment, he touched the nerve of the thigh lightly with the point of a knife and at the same time drew a spark from the static machine. Immediately the muscles of the frog began to twitch violently. Galvani continued to experiment with frogs' legs for years. One day he had several frogs hanging on an iron railing with brass hooks passing through their spinal cords. In his efforts to reproduce the twitching of the muscles he pressed the brass hooks against the iron railing and the muscles responded at once. Although he did not know it, he had produced an

electric cell and a current had flowed through the nerves of the frog, causing the muscles to contract.

Alexander Volta became much interested in these experiments and made a report of Galvani's great discovery to the Royal Society of London. Very shortly he began experimenting himself and to him we owe the first electric battery, or "Voltaic pile," as it was called. He found that copper and zinc placed in sulphuric acid or a solution of common salt and connected in external circuit would generate a continuous electric current. His first battery consisted of alternate pairs of copper and zinc disks separated by moistened pieces of porous paper. Volta did not understand the chemical action of his battery but to him we owe the discovery of current electricity, and the volt, the unit of electrical pressure, has been named in his honor.

THE CONSTRUCTION OF CELLS

1.—An acid cell can be made from a tumbler, some sulphuric acid, a strip of copper and a strip of zinc. Fill the tumbler about two-thirds full of water and pour into it very *slowly* and with constant stirring about one-tenth that volume of concentrated sulphuric acid. Polish off the ends of the copper and zinc with sand paper and attach a two foot length of copper wire to each. Place these in the acid, but do not let them touch.

Bubbles will rise around the zinc strip with the wires separated, but look closely about the copper to see if you can detect bubbles. Now bring the wires in contact and observe the copper strip. A sheath of bubbles immediately envelops the strip but will disappear on breaking the circuit.

The bubbles first appearing on the zinc strip are due to impurities, principally carbon, in the zinc, and constitute what is called "local action." Between each little impurity

and an adjacent particle of zinc an electric current is set up. This combination makes a miniature battery, and there are myriads of them over the surface of the zinc with the result that the zinc wastes away even on open circuit. This can be remedied by using chemically pure zinc or by amalgamating the impure zinc with mercury. To amalgate it, remove the zinc from the tumbler and dip it into a little mercury. By rubbing, the mercury can be made to spread over the entire surface and cover up the impurities.

When the copper and zinc strips are connected in external circuit the zinc goes into solution in the acid, liberating hydrogen, which is driven over to the copper strip where it gives up positive electricity to the copper and bubbles off. When the zinc goes into solution in the acid it carries away with it in the form of little positively charged particles of zinc, called ions, positive electricity and therefore an excess of negative electricity, is left on the zinc strip. Thus the copper comes to be charged positively and the zinc negatively.

This difference of charge is called difference of potential and is measured in volts. Difference of potential is difference of electrical pressure and is exactly similar to difference of water pressure. Just as water will flow from one level to a lower level, or from higher pressure to lower pressure, so electricity will flow along a copper wire from the positive pole to the negative pole. And just as long as this difference of potential is maintained the current will flow, i. e., as long as the acid and zinc remain or until one of them is used up.

The copper is unacted upon by the acid and in this we have the fundamental condition for an electric cell—two dissimilar substances immersed in a solution which will act upon one and not upon the other, or that will act upon one

more rapidly than upon the other. The solution is called the electrolyte.

Touch the ends of the wire to the tongue and describe the result.

Make another cell and join the two in series by connecting the zinc of one to the copper of the other. These will give twice the voltage of one cell alone. Now try the effect of the combination on a door bell or a small buzzer. When not in use remove the zinc strips from the acid.

2. **The Sal Ammoniac Cell.**—Secure a pint fruit jar with a wide mouth and fill it about one-eighth full of sal ammoniac which can be bought at any electrical store. Fill the jar to within an inch of the top with water and dissolve the sal ammoniac by stirring. Remove the carbon from an old dry cell and secure a zinc rod of the same length having a binding post if possible. When the carbon and zinc are placed in the jar and joined in external circuit a fairly strong current can be obtained for a short time. But this cell will polarize rapidly, that is, bubbles of hydrogen will gather on the positive carbon and this almost destroys the action of the cell. This condition may be remedied by dipping the rod in dilute nitric acid occasionally and then heating in a Bunsen flame.

3. **The Bichromate Cell** is the best to make for home laboratory work. In a quart fruit jar place 710 cubic centimeters (about a pint and a half) of water and dissolve in it 80 grams (4 oz.) of chromic acid. Then add slowly with constant stirring 45 cubic centimeters of concentrated sulphuric acid. In this place a heavy zinc strip and a carbon rod provided with binding posts. The larger the surfaces of the zinc and carbon the less will be the resistance of the cell and the more current it will deliver. Long flat strips about 2 inches wide and $\frac{1}{4}$ inch thick are best. The

chromic acid tends to prevent polarization by oxidizing the hydrogen appearing at the carbon electrode. The voltage of this cell is high being about 2.1 volts. Ten of these cells grouped in series will be more than sufficient for most laboratory experiments.

When not in use the zincs must be removed or they will soon be eaten away and this action also destroys the acid.

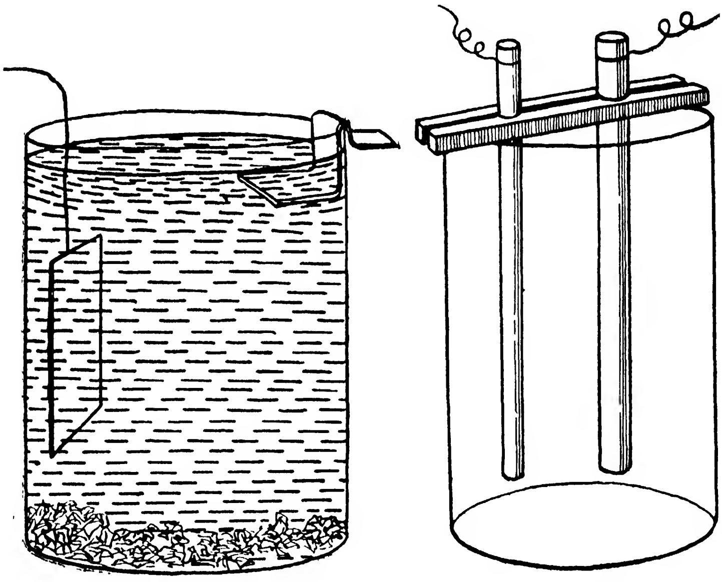


FIG. 82.—A gravity cell and a simple form of electrode holders.

4.—For constant circuit work such as telegraph work none of the above cells is suitable because of polarization. For this purpose the gravity cell is best suited. Secure a battery jar holding about a quart and a half. In this place a sheet of copper about 4 inches wide and 5 inches high having a copper wire soldered to the upper edge. Over the

edge of the jar hang a heavy strip of zinc bent as shown in Fig. 82 and carrying a binding post. Fill to within a half inch of the top with water to which a few drops of sulphuric acid have been added and drop into the bottom a small handful of crystals of blue vitriol or copper sulphate. Place the cell on short circuit and it will soon be ready for use.

Although this cell does not yield a large current, its current and voltage are constant and the cell should be kept on closed circuit. As the copper sulphate is used up add more crystals from time to time. It will be interesting to note the increase in size and weight of the copper sheet as the cell is used.

In any of the above cells holders for the metal or carbon rods may be made from two strips of wood. Cut holes in the ends and clamp then together with short bolts and nuts.

SOME EFFECTS OF THE ELECTRIC CURRENT

Europe again waxed enthusiastic over the discoveries of Galvanni and Volta. A whole new realm of experimental research had been opened up. Everywhere men were eagerly seeking to discover what this new "galvanic influence" might be and what other secrets the electric battery had to reveal. One of the earliest and most distinguished investigators in the new field was Sir Humphrey Davy. Davy was the professor of Chemistry in the Royal Institution of London and already famous because of his invention of the miner's safety lamp. His first great contribution was to explain the chemical action in Volta's cell and to prove that one of the two metals must be acted upon by the acid, or other solution, more rapidly than the other if a current is to be produced.

About this time two Englishmen, Messrs. Nicholson and Carlisle, made the important discovery that the electric current was able to produce chemical changes, and on May 7, 1800, these experimenters succeeded in decomposing water into hydrogen and oxygen. Here were the beginnings of electro-chemistry and the important commercial processes that have developed from it.

Davy was quick to see the possibilities of the electric current in the field of chemistry and immediately began to investigate. In a series of brilliant experiments, now classic, Davy separated the alkali metals, sodium and potassium, from their compounds and then quickly followed this with the metals, calcium, strontium and magnesium. He did this by passing a very heavy current through compounds of these metals in the melted state and thereby developed an electro-chemical process employed a century later at Niagara Falls and throughout the world.

In this work Davy discovered the powerful heating effects of the current and at once began to investigate them further. For this purpose he made an immense battery of two thousand cells and passed the current from it through pieces of "charcoal about an inch long and one-sixth of an inch in diameter." Davy says that when these "were brought near each other (within the thirtieth or fortieth of an inch), a bright spark was produced and more than half of the volume became ignited to whiteness." By drawing the pieces of charcoal apart he was able to produce an arc of dazzling brilliancy four inches long. In this arc the most refractory substances such as platinum, quartz, sapphire, magnesia and lime readily melted or sublimed. Diamond and charcoal vaporized. In 1810 Davy performed this demonstration before the members of the Royal Institution. Here we have the first arc light and the electric furnace, but

their great applications had to wait for Faraday and the dynamo. Batteries were too expensive and wore out too rapidly for such heavy currents. We cannot help but admire Davy and the pioneer work that he did. He was one of the foundation builders of modern science and judged by the high standards of to-day his work was par excellence.

Early in the last century, at the same time that Davy was carrying on his great researches, Luigi Bruguatelli in Italy was inventing the process of electroplating. From this discovery have grown all modern methods of electroplating and the highly important commercial process for the electrolytic refining of metals. So, too, has the process of electrotyping by which books and photographs are put into permanent form for printing.

A FEW EXPERIMENTS ON THE HEATING AND CHEMICAL EFFECTS OF THE CURRENT

1.—For a large number of electrical experiments a *rheostat* for reducing the current will be necessary, and as it will also illustrate the heating effects of the current its construction will be given first.

As shown in Fig. 83 on a wooden base 15 inches long and 6 inches wide mount two end pieces 4 inches square and between these a wooden cylinder 12 inches long and 3 inches in diameter wrapped in heavy asbestos paper. Into the top of one of the end pieces screw a binding post. Secure 210 feet of bare No. 26 German silver wire and fastening one end to the binding post wind this upon the cylinder just as closely as possible without allowing the adjacent turns to touch. Make the other end of the wire secure to the opposite end-piece. Through holes bored in the end-pieces pass a brass rod and on this mount a sliding contact

carrying a binding post. This may be a strip of brass bent to shape and having two holes to permit of slipping over the rod. In the absence of a binding post a wire clip will do.

Now connect this rheostat in series with a half dozen dry cells, or bichromate cells if you have them, and vary the resistance by moving the sliding contact along the rod. When only a few turns of wire are in, note the amount of heat developed and then how this diminishes as more turns are added.

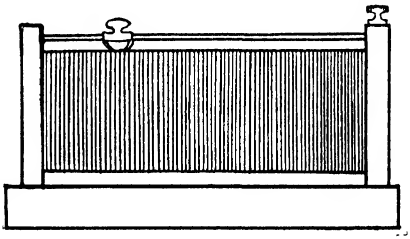


FIG. 83.—A rheostat.

If house current is available connect your rheostat with it, but in doing so be sure that all the resistance is in when you start. Then gradually cut the resistance out but do not cut it all out, or you will blow a fuse. The blowing of the fuse depends upon the heating effect of the current, for when the heat reaches a certain amount the fuse wire melts and breaks the circuit, thus protecting the lamps from an excessive current.

2.—Connect your rheostat and a two-foot length of No. 30 iron wire in series with the house current and gradually cut out the resistance. The wire will become incandescent and begin to burn. If house current is unavailable use a shorter piece of wire and six dry cells.

3.—Cover a board 4 inches wide and 6 inches long with asbestos and screw into each end a binding post. Between the binding posts connect a piece of No. 30 iron wire, allowing it to touch the board. Upon this place a little heap of gunpowder and by means of long wires connect the board

with six or eight dry cells. The heat developed will ignite the powder.

A pair of wires with wire clips attached to their ends will be found very convenient for making quick connections.

4.—Between the binding posts of the board in experiment 3 place wires of different materials and with each material use wires of varying diameter. Also in each case by means of the rheostat vary the amount of current used, In this way you will learn how the kind of material and its size and the quantity of current used affect the amount of heat developed.

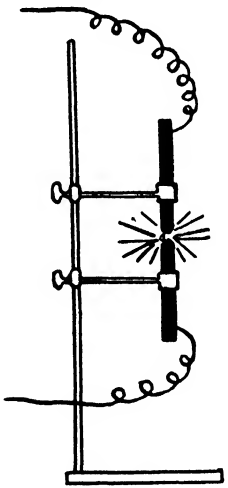


FIG. 84.—The electric arc.

5.—Wind a length of No. 26 German silver wire about a lead pencil so as to form a spiral and when it has set remove and immerse in a tumbler or can of water. Connect the ends of the loop with 8 dry cells or in series with the rheostat and the house current. The heat developed will cause the water to boil. Electric hot point heating irons are made in this way.

6.—Secure two electric light carbons and fasten to one end of each a heavy copper wire. Mount these carbons in a vertical position on a ring stand by means of clamps as shown in Fig. 84 and insulate the carbons from the clamps with asbestos paper. Now connect the carbons in series with the rheostat and the house current, having the resistance all in at the start. Bring the carbons together lightly and gradually cut out the resistance until the ends begin to glow. Draw the carbons apart slightly and cut out more resistance. Draw

them still further apart and if necessary cut out additional resistance. An arc of dazzling brilliancy will be formed and in it you can put pieces of various metals, lime, quartz, etc. These may be held in the arc by means of iron tongs. This is the sort of an arc that Davy produced.

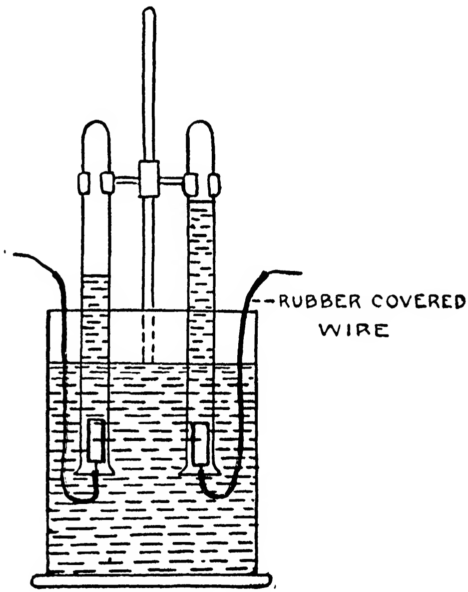


FIG. 85.—Electrolysis apparatus.

This experiment should not be done, however, without colored glasses.

7. **Electrolysis of Water.**—Arrange a battery jar, ring stand, clamps and two large test tubes as shown in Fig. 85. Two pieces of platinum foil will be necessary for this experiment, but they may be small. Make a tiny hole in each foil and through it draw a copper wire, bending the end over.

Arrange these as shown in the figure. The wire must be rubber covered in order to insulate it.

Make a solution of sulphuric acid and water having about one part of acid to twenty parts of water. *Always pour the acid into the water.* Have the jar about three-fourths full of the solution and invert over the platinum electrodes, test tubes filled with the same and make secure with the clamps.

Connect the wires from the platinum electrodes with 6 dry cells and allow the action to continue until one of the platinums is nearly exposed. Remove the test tube having the larger volume of gas and keeping the mouth down apply a lighted match to it. This is hydrogen. Loosen the clamp from the other test tube and placing the thumb over its mouth remove it. With the mouth up insert a glowing splint into the gas and it will be kindled into a flame. This is oxygen.

This experiment may be performed with copper electrodes, but only hydrogen will be obtained for the oxygen will unite with the copper.

8.—Repeat the above experiment using a solution of sodium sulphate instead of sulphuric acid and color this with a solution of blue litmus. Upon passing the current the solution in the hydrogen test tube will remain a deep blue, but in the oxygen test tube it will turn red. When the colors have appeared reverse the connections and the colors will also reverse. Acid is formed in the red test tube and base in the blue.

9. **Copper Plating.**—In an oblong battery jar about 10 inches long and 5 inches square on the end as shown in Fig. 86, place a saturated solution of copper sulphate. To prepare the solution crush the crystals and stir them with water allowing the mixture to stand overnight. Across

the ends of the jar place small pieces of wood carrying binding posts or simply place a heavy bent wire across. To one terminal attach a piece of heavy sheet copper about two inches square and to the other terminal a door key or some other object which you wish to plate. This object must be polished with rouge cloth first so as to free it from dirt and grease.

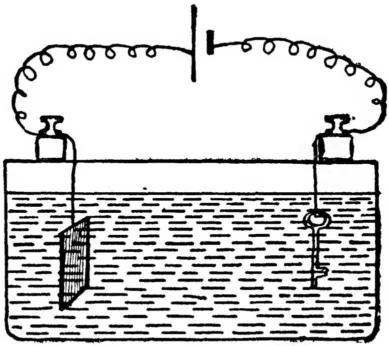


FIG. 86.—Copper plating bath.

For the source of current either three gravity cells or two storage cells connected in series are best.

The positive pole should be connected to the sheet of copper and the negative pole to the object to be plated. In a short time a bright, firm deposit of copper will be made.

Just as fast as copper is driven out of solution on to the object to be plated more copper is brought into solution from the copper sheet which wastes away and must be replaced from time to time. If the deposit is slow in forming, bring the electrodes closer together.

10. **Nickel Plating.**—An object to be nickeled is usually copper plated first. For this experiment use an electric light carbon and to get the coat of copper place it at the negative pole of the copper plating bath for a few minutes. Remove and polish with rouge cloth.

Now prepare a nickel plating bath by dissolving in one liter of water (about one quart) 72 grams of nickel ammonium sulphate, 23 grams of ammonium sulphate and 5 grams of crystilized citric acid. A gram is about one-seventh

of an ounce. Now add household ammonia to this solution slowly and with stirring until it will only just barely turn blue litmus paper red, but do not add more than this amount. The solution must be left acid.

Arrange the nickel plating bath the same as for copper plating, placing the copper covered carbon at the negative pole and a strip of nickel at the positive pole. Connect with three gravity cells or two storage cells as before and allow the current to flow until a good deposit has been made. Remove and polish with rouge cloth. In this experiment a smaller jar may be used and the plate and carbon placed closer together.

11. **Electrotyping.**—Where a large number of copies of any publication are to be printed the soft type metal is not durable enough to give clean-cut impressions. Therefore a wax impression of the type is obtained and electrotypes are made.

Upon a strip of sheet lead 6 inches long and $1\frac{1}{2}$ inches wide place pieces of beeswax and melt them over a small Bunsen flame. Allow the melted beeswax to run evenly over the sheet of lead forming a layer $\frac{1}{8}$ of an inch thick.

When the wax is hard rub it over thoroughly with powdered graphite, using a soft cloth. Dust the object you wish to electrotype with graphite and press it into the wax until a clean-cut impression is made. Now dust this impression again with graphite and rub to a smooth shiny surface. Attach a wire to a hole in the top of the lead strip and be sure the graphite extends onto the lead so as to make a continuous conducting surface.

Place the lead strip at the negative pole of the copper plating bath and allow the current from two gravity cells or one storage cell to run for 24 hours. At the end of this time remove the lead strip, wipe it dry, soften the beeswax

over the flame and strip off the thin deposit of copper. If desired, back it with melted tin.

ELECTRO-MAGNETISM

A discovery of the first importance was made by Hans Christian Oersted a Danish physicist, in the year 1819. One day as he was lecturing before his class it occurred to him to place a wire carrying an electric current over a compass needle and parallel to it. To his surprise the needle turned and set itself in a nearly east and west direction at right angles to the wire. When he reversed the current he found that the needle was deflected in the opposite direction. For the first time positive proof had been given of the very close relationship between magnetism and electricity. Many had suspected it, but no one before had been able to demonstrate the fact. When a little later it was also shown that a coil of wire through which an electric current is flowing, itself, possesses a magnetic field the basis was laid for a new realm of electrical research.

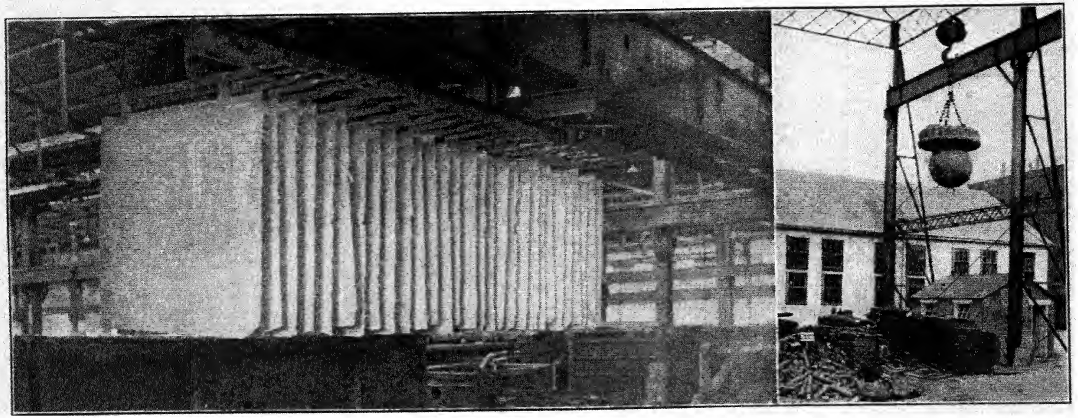
It is hard for us to understand in these days of marvelous achievement the very great interest these early discoveries made throughout Europe. But simple as these facts now seem and familiar as they are to every schoolboy they are the great epoch-making discoveries without which later progress would have been impossible.

In the year following Oersted's great discovery a Frenchman, André Marie Ampère, found that a coil of wire through which a current flows acts like a magnet and will attract or repel a similar coil according to the relative directions of the current in the two coils. If the current in the coils flows in the same direction there is attraction and if in the opposite direction repulsion.

In this same year Arago, another Frenchman, whirled a copper disk placed in a horizontal plane beneath a suspended compass needle and found that the needle would whirl too. It remained for Faraday to explain this action a number of years later, but here is the first instance of induced currents, the basis of present day commercial electricity.

In 1824 Sturgeon made the first electro-magnet. He wound a number of turns of insulated copper wire upon a soft iron core and found that its attraction for other pieces of iron was very great. Joseph Henry, the pioneer worker with current electricity in this country, shortly after this made electro-magnets of great lifting power. With one magnet weighing $59\frac{1}{2}$ pounds he was able to lift a ton of iron. A little later Samuel F. B. Morse, equipped with the idea of the electro-magnet, invented the telegraph, the first great commercial application of electricity. Since then a host of applications of this simple device have been made and without it many of the most useful electrical inventions would have been impossible. In capacity the electro-magnets range from the delicate relay actuated by the very feeble currents of long distance telegraph lines to the large commercial lifting magnets capable of sustaining many tons of iron and steel. Lifting magnets require no grappling hooks. A crane lowers the magnet until it comes in contact with the mass of iron and the closing of a switch produces millions of invisible magnetic lines of force which more securely than hooks of steel grapple the iron and hold it fast. When the mass of iron is to be released the circuit is broken and these mysterious lines of force immediately disappear.

An electro-magnet is a temporary magnet and possesses magnetism only so long as the current flows in it. The core of the magnet is soft iron having very great capacity for absorbing and concentrating the lines of force but instantly



Electrolytic refining of copper and 10-ton lifting magnet.

losing its magnetism when the circuit is broken. A coil of wire without a soft iron core is called a solenoid. It possesses a magnetic field when a current is passed through it as Ampère showed, but the intensity of this field is many times less than it is with a soft iron core.

A decade later Faraday was to show a still more intimate relation between electricity and magnetism and to lay the foundation for modern dynamo currents.

EXPERIMENTS ON ELECTRO-MAGNETISM

1.—In order to repeat *Oersted's experiment*, if you do not already have one, make a compass similar to the one shown

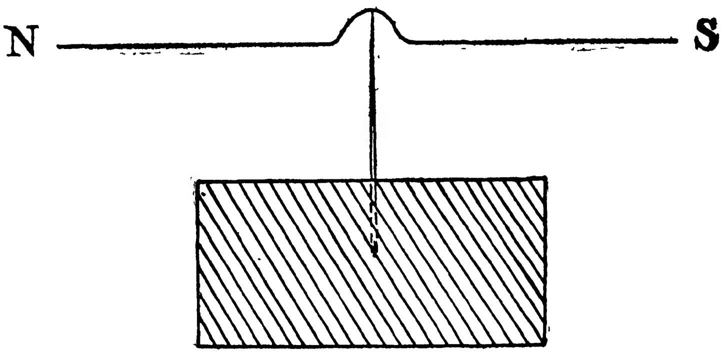


FIG. 87.—An easily constructed compass.

in Fig. 87. To do this secure a piece of steel watch spring 4 or 5 inches long and after having straightened it out make a dent in the center with a nail punch and bend as indicated. To magnetize this, stroke it from the middle toward one end with the positive pole of a bar magnet and from the middle toward the opposite end with the negative pole. Cut a quarter-inch thickness from the end of a large cork

and thrust the blunt end of a sewing needle into this and mount upon it the magnetized watch spring. If it does not balance trim off the ends with cutting pliers until it does.

Now connect two dry cells in series with a two-foot length of copper wire and hold it over the compass needle in a north and south direction. Note the deflection of the needle. Repeat with the current flowing in the opposite direction and note that the deflection is also in the opposite direction. Knowing that the current flows from the positive pole to the negative, see if you can work out a rule for determining the direction of a current by means of the deflection of a compass needle.

Hold the wire joining the cells in a vertical position and near to the compass. Note the effect on the needle. Reverse the direction of the current and note the effect.

It is upon experiments of this kind that Wheatstone's telegraph was based and also one type of electrical measuring instruments.

2. **Ampère's Experiment.**—Make two coils about 4 inches across of 200 feet each of No. 26 cotton-insulted copper wire and wind with tape to hold in position. Connect one of these coils with 6 or 8 dry cells and holding the coil by the two lead wires present one face of it to the north pole of a compass needle. Note the attraction or repulsion. Then turn the coil about and present its other face to the compass needle.

Connect each coil with a half dozen dry cells and suspending each by the lead wires bring their faces close together. They will either attract or repel each other. Now reverse one of them and observe the effect. If there was attraction before there will be repulsion now.

3. **Effect of Soft Iron on the Strength of a Magnet.**—Place some iron filings or small iron nails on the table and

bring one of the coils of wire near them. Have the coil connected with a dozen dry cells or better in series with the rheostat and the house current. Note the lifting power.

Now thrust through the coil and into the filings a large soft iron bolt. Break the circuit and note how the magnetism immediately disappears. Holding the end of the bolt about a half inch above the filings make the circuit and observe the effect.

4. **A Lifting Magnet.**—An electro-magnet that will lift well above 100 pounds and which may be connected in safety to a 110-volt lighting circuit may be made as follows:

Go to a blacksmith shop and secure a *soft iron* rod about 1 inch in diameter and 4 inches long. Smooth off the ends and slip over the rod a piece of stock-fiber tubing followed at each end by a tight-fitting washer of the same material about three inches in diameter. Leave the ends of the rod uncovered as shown in the diagram. The fiber tubing and washers will make an excellent spool upon which to wind the wire. Now wind upon this spool 1,200 feet of No. 26 double-covered copper wire. This may be wound by hand in a short time or a reel can be easily made to hasten the process. To guard against unwinding, the ends of the wire may be taken out through holes punched in one of the washers. Provide a hook for handle or for attaching to a system of pulleys by drilling and threading a hole in one end of the soft iron core into which screw a threaded hook of proper size. A *soft iron* hanger for the opposite end may be made in a similar way.

The resistance of the coil of wire is such that the current flowing in it with 110 volts pressure will be about 2 ampères which is well under the capacity of an ordinary house fuse. The current should never be allowed to run for more than a few minutes at a time, though, as the heat developed

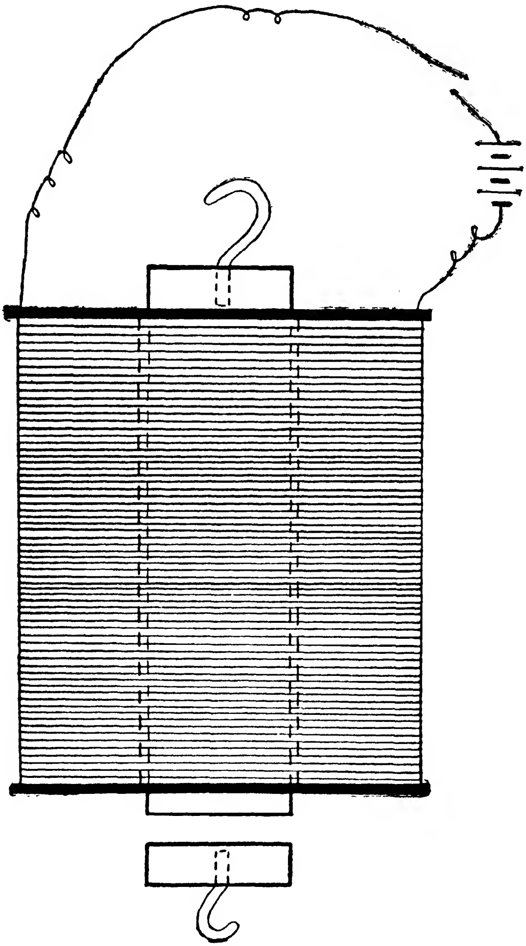


FIG. 88.—A lifting magnet.

might char the insulation and short circuit the coil. A simple switch to make and break the circuit may be easily devised.

When complete, try its lifting power on nails, bolts, spikes and other pieces of iron. To test its strength make a hanging platform by boring holes in each corner of a board 18 inches square and suspend from the hanger hook by ropes passed through the holes. Throw the switch and pile on heavy objects until the hanger with its load, becoming too great for the strength of the magnet, drops off. You will be surprised to discover what a little giant you have made.

With a load of nails clinging to the magnet break the circuit and note the immediate loss of magnetism. You will understand then how valuable large commercial lifting magnets are for loading steel rails, pig iron and castings in steel mills and foundries. No grappling hooks are necessary, only the throwing of a switch and when the load has been swung into position it may be released just as easily and at a moment's notice by the breaking of the circuit. Mysterious and invisible, these magnetic lines of force may be called into instant action and better than hooks of steel they seize their load and deposit it in any desired spot.

5. **A Buzzer.**—Make an electro-magnet using 100 feet of No. 26 cotton-covered wire in the same manner as the large lifting magnet in the previous experiment and mount it on a wooden base as shown in Fig. 89. Heat one end of a steel clock spring to draw the temper and drill a hole through it. Bend and mount as shown. In one end of the base insert a wooden post and extend from the top of it a brass arm carrying a contact screw. Adjust this screw until it just touches the bent spring. Connect one end of the magnet wire to the screw at the base of the spring and the

other with a battery. Connect the other battery wire with the adjustment screw.

When the circuit is made the magnet draws the spring away from the contact point. This breaks the circuit and the magnet loses its magnetism allowing the spring to fly back in contact with the screw, again making the circuit. This process is repeated over and over. The working of this simple buzzer is exactly the same as that of an ordinary door bell.

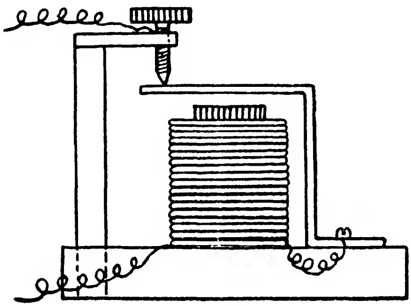


FIG. 89.—A buzzer.

6. **Magnetic Permeability.**—Connect up the large lifting magnet described in experiment 4 with the house circuit and over one pole hold a six-inch square of window glass upon which iron filings have been placed. Make and break the circuit noting the very marked effect upon the filings. Move the glass about and observe how the filings tend to remain near the pole.

Repeat the above experiment using a square of wood instead of glass. This fact, that lines of force will pass through such substances as glass and wood, is called magnetic permeability.

Now substitute a thin piece of sheet iron and note the different effect. Why is this?

THE STORAGE BATTERY

Among the most important commercial applications of the chemical effects of the current is the modern storage

battery. As early as 1801 it was discovered by Gautherot that platinum wires used as electrodes in the electrolysis of water would send a current in the opposite direction if the battery were removed. A number of other men including Faraday experimented with secondary cells, as they were called, but not until Planté of France in 1860 developed the lead cell was a successful storage battery invented.

While the storage battery may be charged by passing current into it and it seems to "accumulate" electric energy, there is of course no actual storing of electricity. When the current is passed, chemical changes take place in the electrolyte and on the plates of the battery and it is really chemical energy which is stored. When the charging circuit is broken and the battery is connected in external circuit, a reverse set of chemical changes occur and a current flows from the cell in the opposite direction to the charging current.

Planté's storage cell consisted of two lead plates placed in a solution of sulphuric acid and connected to a source of current. After the current had flowed for a short time one plate was found to be coated with lead oxide while the other remained unchanged. When these plates were connected in external circuit the cell was found to develop an electro-motive force of a little more than two volts. Later it was found that the capacity of the cell could be increased by grooving the plates and filling the grooves with a paste of oxides of lead. Red oxide of lead is used on the positive plate and litharge on the negative.

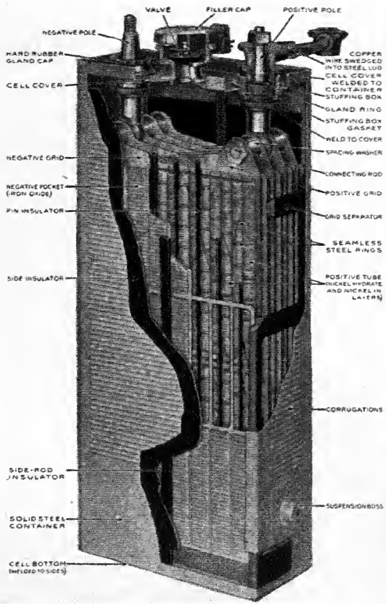
While the lead storage cell has come into wide use and has met a large number of very real needs in a fairly satisfactory manner, it is not an ideal cell. It possesses a number of disadvantages as the users of this cell only too well know.

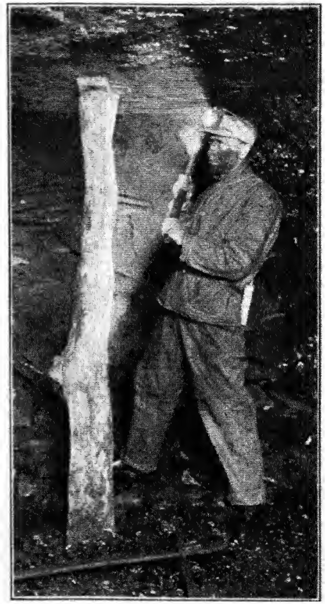
Being made of lead its weight is very great. The sulphuric acid must be of definite specific gravity. The cell must not be discharged too low, and over charging or very rapid charging are to be avoided. The cell cannot stand during periods of idleness in the discharged condition. It must be left charged and frequently recharged during these periods. In spite of the best care the plates of the lead cell will permanently sulphate to some extent and to just that extent its life is destroyed. Their comparatively low cost and high voltage, however, have made lead cells very popular and with proper care they will last a long while.

One of the most remarkable products of modern inventive genius is the *Edison Storage Battery.* After eight years of research and nine thousand experiments the great inventor gave to the world a storage battery that well deserves the description, "Built like a watch: rugged as a battleship." It is fool proof, and after nine years of severe testing is apparently indestructible. It may stand charged or discharged, be discharged to zero voltage, charged in the reverse direction or subjected to any treatment, however severe, without injury. It is light and easily portable.

The Edison cell employs an electrolyte of caustic potash or soda instead of sulphuric acid. The positive plate is made up of a series of perforated metal tubes packed with alternate layers of very light flake nickel and nickel hydrate. These tubes are made of steel and electroplated with nickel. The negative plate consists of a series of perforated steel jackets nickel plated and packed with iron oxide. The caustic potash solution makes its way through the perforations in the tubes and pockets coming in contact with these materials. On charging, the nickel hydrate changes to an oxide and the iron oxide is reduced to a metallic iron.

Uses of Storage Cells.—Both lead and Edison storage





Edison's storage battery and its application in the miner's lamp.

cells have many important uses. In power plants large batteries of storage cells are charged when the demand upon the dynamos is light and then when the demand is heavy these cells are placed in parallel with the dynamos to help carry the load. In periods of very light load the storage cells are frequently able to carry it alone. In times of accident storage cells serve as an auxiliary supply to be switched in at a moment's notice.

For the small electric light plant in rural communities storage cells are indispensable. They may be charged from a dynamo run by a gasoline engine or a small water fall. Much water power on farms throughout the country goes to waste which at comparatively small expense might be converted into electric energy and by means of storage cells made to supply an abundance of light and power. Such a storage battery plant on the farm will not only light the house and outbuildings but will also supply power for the laundry, pump water, run motors for operating milking machines and cream separators, feed cutters, wood mills, grindstones and a score of other appliances.

The storage battery is also extensively used to operate electric trucks, for train lighting and railway signaling, for miners' lamps, submarines, wireless work, yacht lighting, automobile ignition, lighting and self-starting service, laboratory work and many other uses. For driving submarines a large number of huge storage cells each having a capacity of 3,500 ampère-hours is employed.

A Simple Storage Cell.—Into a tumbler two-thirds full of water pour about one-tenth of that volume of sulphuric acid slowly and with constant stirring. In this by means of wooden clamp holders suspend two strips of heavy sheet lead about 5 inches long and 1 inch wide. Connect the cell with 3 dry cells for about five minutes. Remove the lead

strips and observe their color and appearance. Replace them in the acid and connect the cell with a buzzer or electric bell.

FARADAY AND INDUCED CURRENTS

Important as battery currents were and are yet, the very great electrical progress of the nineteenth century and since would have been utterly impossible without some other means of generating electric pressures and currents. Even storage batteries were not a commercial success until dynamo current was available for charging them. But Oersted, Ampère and Arago had made discoveries which the genius of Michael Faraday used as the basis for still further experiment, and in a series of epoch-making discoveries in the year 1831 he laid for all time the foundations of commercial electricity.

No higher type of man can be found in all history than Michael Faraday. Quiet, unassuming, of childish gentleness and simplicity, with no thought of private gain and actuated only by an intense love of truth, he devoted his life in unselfish loyalty to the advancement of science. Had he sought financial fortune, it was within his grasp. Millions have been made from inventions based on his discoveries. Faraday's passion was not for money but rather adding to the sum total of human knowledge, and no single investigator ever added more. His researches were not confined to electricity but covered a wide range of subjects in both chemistry and physics. Whenever a great discovery had been made, he left its commercial development to other men and turned with renewed enthusiasm to a fresh field of research. So long as the pursuit of truth engages the interest of men, the name of Michael Faraday

will take first rank in the record of scientific achievement. In this day of intense commercialism and keen rivalry it is good to contemplate such utter forgetfulness of self and complete devotion to truth for truth's sake.

Son of a blacksmith and apprenticed to a bookbinder, Faraday attended four lectures by Sir Humphrey Davy and became so deeply interested in the new field of scientific discovery to which these lectures introduced him that he applied to Davy for a position as laboratory assistant in the Royal Institution. Although discouraged by Davy from entering upon such a life, Faraday received the coveted appointment and at the age of 22 began a period of service for the cause of science which was to last without interruption in the same laboratory for 46 years.

It will be remembered that Arago had caused a compass needle to rotate by whirling rapidly beneath it a copper disk. Why this rotation should occur was a complete mystery to Arago and all others except Faraday, and even with him the solution of the problem was only a conjecture. He suspected that electric currents were induced in the copper disk and that these currents acting upon the opposite ends of the needle caused it to rotate. With the scientist all theories must be subjected to experimental proof, and Faraday immediately set to work to verify his suppositions. He mounted a large copper disk so that he could whirl it between the poles of a powerful horseshoe magnet. Around the axis of the disk he passed a copper wire and carried it to a sensitive galvanometer. The other galvanometer wire he held against the edge of the disk. Then as he whirled the disk, just as Faraday had suspected, the galvanometer needle was deflected, showing the presence of an electric current. Thus Faraday had established the fact that a magnetic field may be made to generate electricity. This

is really the converse of Oersted's discovery that a current bearing conductor possesses magnetic lines of force.

In this rotating disk of Faraday's we have the first crude dynamo. Not much to invent you may think, so simple and imperfect, so feeble in its output, and yet within it lay the germ of every generator of later times from the toy dynamo of the playroom to the huge generators at Niagara Falls. It is not the perfection of an intricate mechanism which must be recognized as a work of genius, but the discovery of the principle which underlies it. Very often the discovery of the principle and its application in a suitable machine are made by the same experimenter, but we should always remember that the principle must precede the application.

Faraday substituted a rotating coil of wire for the copper disk and thus made a real dynamo but the mechanism was so crude and the losses in generating the current so great that commercial success was impossible. Faraday, however, had blazed the way, and later inventors simply applied with greater perfection of mechanical details the principle which he had discovered.

Even before the experiment with the rotating disk Faraday had discovered the law of induced currents. He kept asking himself the question—"If an electric current will magnetize iron, why will not a magnet produce an electric current?" And again by direct experimentation he sought an answer to his question. He connected a coil of wire to a sensitive galvanometer and thrust into it a strong bar magnet. As he did so he observed a slight throw of the needle. But contrary to his expectation the needle returned to its position of rest as the movement of the magnet ceased. He observed another throw of the needle, however, as he withdrew the magnet and thus discovered that a coil

of wire will have a current induced in it only when the lines of force which induce the current are made to cut across the coil.

Faraday next set out to discover whether or not the magnetic field about one coil through which a current was flowing would induce a current in another coil near to it but insulated from it. To determine this he wound two coils of wire, one of 60 feet and the other of 72 feet, on the same wooden spool and insulated them from each other with twine string and calico cloth. One of these coils he connected with a galvanometer and the other with a battery of ten cells. As the current flowed through the coil not the slightest effect upon the needle could be observed, but when the circuit was broken there was the throw of the needle. A current was surely induced, and just at the instant that the circuit was made again there was another throw of the needle. Faraday had established the fact that the magnetic field of one current will induce a current in an adjacent coil provided this magnetic field is changing. Faraday observed, too, that the throw of the needle was in one direction when the circuit was made and in the opposite direction when it was broken. Evidently the induced current flowed in opposite directions in the two cases. Here was the whole story of induced currents. When the circuit is made the lines of force surge outward from the first or primary coil and cut across the turns of the secondary coil, inducing a current in one direction. When the circuit is broken the lines of force surge inward again, cutting the secondary and inducing a current in the opposite direction. In this simple apparatus Faraday gave to the world the first induction coil and the first transformer. Wireless telegraphy, the long distance transmission of electric power, the telephone, the X-Ray and numerous other applications of electricity

were made possible by the perfection of these two electrical inventions. Both are described more fully in the chapter on wireless.

Knowing the influence of soft iron on the intensity of an electro-magnet, Faraday substituted a soft iron ring for the wooden spool, winding the primary upon one half and the secondary upon the opposite half. The result was a very much stronger induced current. He made the number of turns on the secondary greater than on the primary and again increased the voltage. In one experiment he connected the terminals of the secondary to two pencils of charcoal resting lightly against each other and obtained an electric spark, the first discharge of an induction coil ever made.

These epoch-making discoveries which laid the foundation for nearly a century of unparalleled progress were made by Faraday within the short space of ten days, but they had been preceded by nine years of experimental research. It is to the man who is willing to devote himself to years of patient research that the world owes its greatest discoveries and inventions. Very frequently so-called genius is simply another name for drudgery.

EXPERIMENTS WITH INDUCED CURRENTS

1. *The Principle of Induction.*—Wind about 500 turns of No. 22 insulated copper wire into a coil 2½ inches in diameter and make secure with binding tape. Connect the ends of the coil with a watch case telephone receiver and holding it to the ear thrust into the coil one pole of a strong bar magnet. A distinct click will be heard. Withdraw the magnet and a second click will be heard.

Instead of the telephone receiver a galvanometer may

be made by winding into a somewhat elongated coil 100 turns of the same wire as above. Place this in a vertical plane with the long axis parallel with the compass needle. Now suspend inside the loop a magnetized sewing needle by means of a silk thread. Connect the ends of the two coils and thrust the magnet as before. At each cutting of the turns of wire by the lines of force there will be a quick throw of the needle and it will be observed that the deflections in the two cases are in opposite directions.

2. *A Minature Transformer.*—On the opposite halves of a soft iron ring about 5 inches in diameter wind two coils. The primary coil should contain about 15 feet of No. 14 insulated copper wire and the secondary 500 feet of No. 26 wire. Connect the primary with a half dozen dry cells and the secondary with the telephone receiver or galvanometer. Now make and break the primary circuit. At each make and break a distinct click of the receiver or throw of the needle will result. This is a minature transformer. Wet your fingers and hold them on the terminals of the secondary as the primary is made and broken.

3. *Lighting a Lamp by Induction.*—If alternating current is available a very interesting experiment to show the effects of induction can be performed. Wind into a coil about 4 inches in diameter 1 pound of No. 18 bell wire and cover it with tape. Connect the ends to a small 4 volt glow lamp. Now connect the large lifting magnet, described in *experiment 4* under electro-magnetism, with an alternating current of 110 volts and hold over one end of it the coil and lamp. The current induced in the coil will light the lamp. The rapid alternations of the current will have the same effect as the making and breaking of the circuit in the previous experiment. Although there is no connection between the two coils the lamp will light.

For this experiment an electro-magnet with half as many feet of wire would be even better.

4. *A Simple Transformer.*—Transformers are of two kinds—"step-up" and "step-down." The step-up transformer takes an alternating current of low voltage and large quantity and transforms it into a current of high voltage and small quantity for long distance transmission of electric power, while a step-down transformer performs the reverse operation at the other end of the line.

Neglecting the small loss of energy in the transformer itself there are just as many watts in the primary as in the secondary, but the voltage in one will be low and the amperage high, while in the other the opposite will be true. Now the watts are equal to the volts times the amperes. Therefore, if in the secondary of the transformer the voltage is increased 10 times over what it is in the primary, the number of amperes must be only one-tenth as great as in the primary, for the product of the volts and amperes in each coil must be the same. The voltage in the two coils of a transformer will depend upon the relative numbers of turns of wire. If the primary has 100 turns and the secondary 10,000 then a current of 100 volts pressure and 10 amperes in the primary will be changed into a current of 10,000 volts and $^1/_{10}$ of an ampere in the secondary. It will be observed that the product of the volts and amperes in each case is the same.

For running electric trains and small motors it is very convenient to be able to step down the voltage of the alternating current of the house lighting circuit to 6 or 10 volts. Suppose it is wanted to build a 110 watt transformer to change from 110 volts to 10 volts. Since our transformer is to have a capacity of 110 watts and the voltage of the primary circuit is 110 volts the number of amperes in the

primary will be 1. Therefore, looking in a wire table we will select a wire having a safe carrying capacity of 1 ampere which will be about No. 26. Although Ohm's law of resistance does not strictly apply to alternating currents we will assume that it does. Since the current times the resistance equals the volts in order to get 1 ampere with 110 volts we shall need 110 ohms resistance. Allowing for the fact that this is alternating current 100 ohms will be

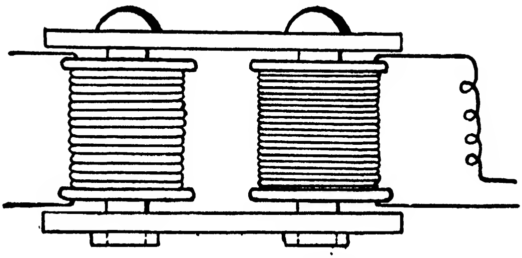


FIG. 90.—A simple transformer.

more nearly correct. Now the table shows that 1 foot of No. 26 wire has a resistance of .04 ohm. Therefore to get 100 ohms we shall need 2,500 feet.

For the cores upon which to wind the coils select two bolts each 4 inches long and join them together with soft iron strips. Upon each bolt place a piece of stock fiber tubing and at each end a tight fitting washer of the same material. Now wind upon one of these spools 2,500 feet of No. 26 double covered copper wire and count the number of turns. Cover every layer with a sheet of stiff writing paper. The ends of the wire may be passed through holes in the washers.

Since the voltage of the secondary is to be $^1/_{11}$ that of the primary the number of ampères will be 11 times as great or in this case 11. Looking in the wire table we find

that No. 14 wire comes the nearest to having a safe carrying capacity of 11 ampères. Since the voltage in the primary is 11 times greater than it is to be in the secondary, there will need to be but $^1/_{11}$ as many turns in the secondary coil. Therefore, knowing the number of turns on the primary, wind $^1/_{11}$ of this number of turns of No. 14 wire on the opposite spool. The construction will become clear from Fig. 90.

The secondary coil may be connected with the motor to be run and the primary with the house circuit. To reduce the voltage still further connect in series with the primary and motor or other apparatus a small resistance.

DYNAMOS AND MOTORS

It was more than thirty years after Faraday's simple disk dynamo had demonstrated the possibility of an induction generator before a commercial dynamo was invented. About 1865 Dr. Henry Wilde of England invented a separately excited dynamo which was operated by a steam engine and developed currents of considerable strength. Other experimenters immediately went to work and in fifteen years the present day commercial dynamo was well on the road to perfection.

The parts of a dynamo will become clear from a consideration of Fig. 91. At A we have a simple alternator. The poles of the field magnet are at N and S. The loop ABCD constitutes the armature. The collecting rings and brushes for taking off the current are shown at the end of the shaft. The lines of force from the field magnet pass from N to S and as the armature is turned in the direction indicated by the arrow it is made to cut the lines of force and a current is induced in it. This current flows about the loop in the

direction shown and through the external circuit from the positive brush to the negative brush. When this loop has turned through 90 degrees from its present position, the sides of the loop, AB and CD, will not be cutting the lines of force but will be moving parallel with them and therefore no current will be flowing in the loop. In the next instant, however, AB which has been rising through the

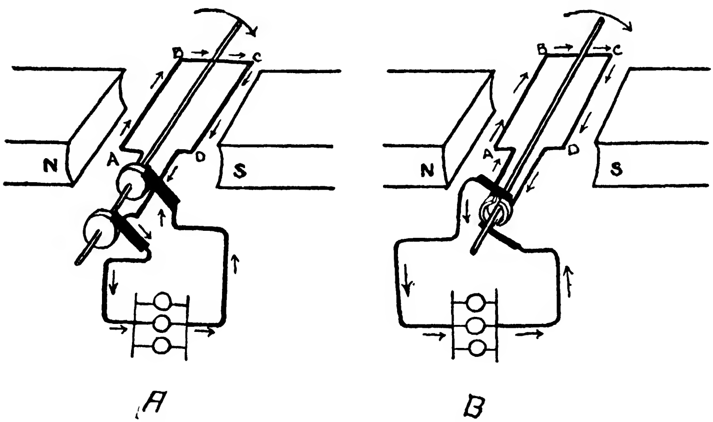


Fig. 91.—The construction of the dynamo.

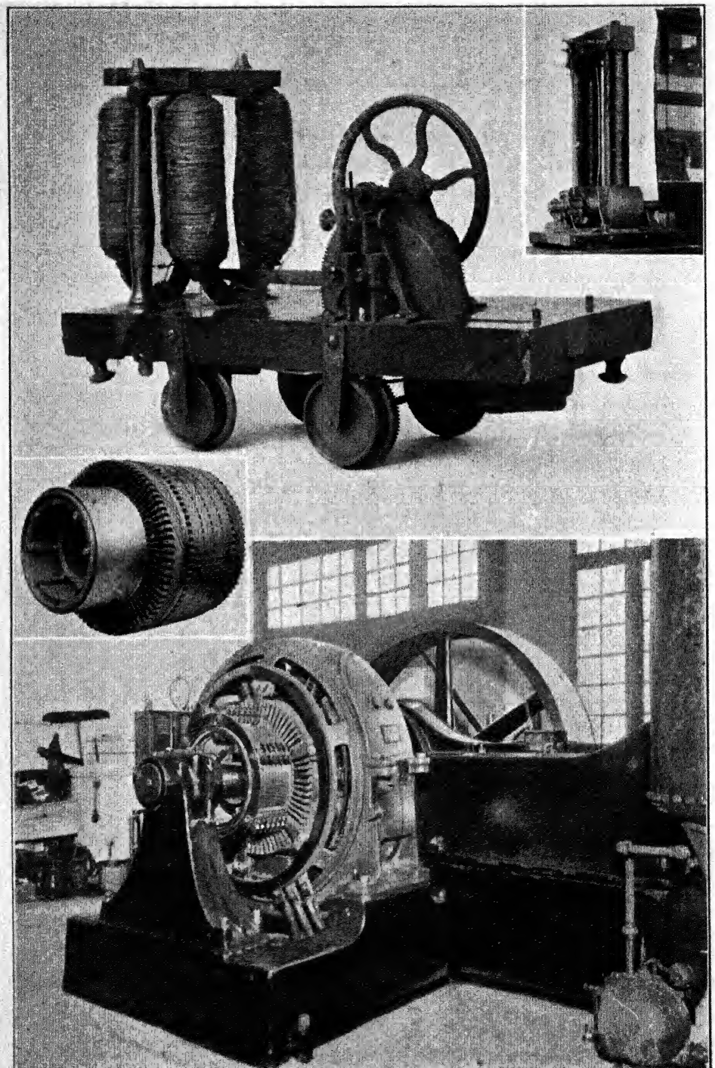
lines of force will be falling and CD which has been falling through the lines of force will be rising. Therefore at this point the current in the loop and also in the external circuit will reverse its direction. As can be seen this will happen twice during each revolution and therefore such a generator will give an alternating current.

The current induced in the armature of any dynamo will be alternating, but it may be taken off in the external circuit in one direction, and a generator built to do this is called a direct current generator. It differs from the alternating type in having a commutator ring to which the ends

of the armature loop are joined instead of collector rings. This commutator ring is split and the two segments are insulated from each other and from the shaft. The brushes are so placed that, just at the instant that the current reverses in the loop, the segments of the commutator change contact with the brushes. The segment that has been in contact with the positive brush moves over and touches the negative brush and the other segment comes in contact with the positive brush. Thus, although the direction of the current changes in the armature, it does not change in the external circuit. The diagram of a simple direct current generator is shown at B in Fig. 11.

In the dynamos built by Wilde and other experimenters of that time electro-magnets were substituted for the permanent steel magnets used by Faraday. But these magnets had to be separately excited by small generators with permanent magnets. The first improvement upon this method was made by Siemens, a German, who found that a shunt circuit taken from the armature and passed about the field magnets would furnish the necessary current for this purpose and still leave an abundant supply for the external circuit. He also improved the armature by winding the wire lengthwise of a soft iron drum. A little later several coils of wire were wound upon the drum of the armature, placed at angles to each other and connected in series through the segments of the commutator ring, there being as many segments as there were loops. This produced a more uniform voltage because at any moment the various loops would be cutting the lines of force at all angles and therefore inducing voltages from a minimum to a maximum.

One of the early troubles with the Siemens dynamo was excessive heating of the core, but this was remedied by



Early Edison dynamo, Colton motor and General Electric direct-current armature and generator.

Gramme of France who reinvented the ring armature of the Italian, Pacinotti, and produced in 1868 the first really successful dynamo for strong currents. This ring was a hollow soft iron cylinder upon which the wire was wound, and it will be seen that but one-half of each loop cut the lines of force. For this reason the drum type is more widely used now, but it is made up of a large number of soft iron sheets cut to shape and insulated from each other. This reduces the heating effects in the core by preventing very largely the induced "eddy" currents which cause them.

Edison made very great improvements and introduced the compound dynamo. In the shunt wound dynamo a decided drop in voltage occurred when a large demand was made upon it. As the current in the external circuit increased, less flowed through the shunt circuit about the field magnets and there being fewer lines of force less voltage was generated. To remedy this Edison passed the wires leading to the external circuit in a number of turns about the field magnets, too, and therefore whatever the change in the current in the external circuit the strength of the field remained constant. A change in one circuit was balanced by a change in the other. Edison also introduced the practice of placing the dynamo on the same shaft with the engine which drives it. For electric lighting and where constant voltages must be maintained these improvements were of immense importance.

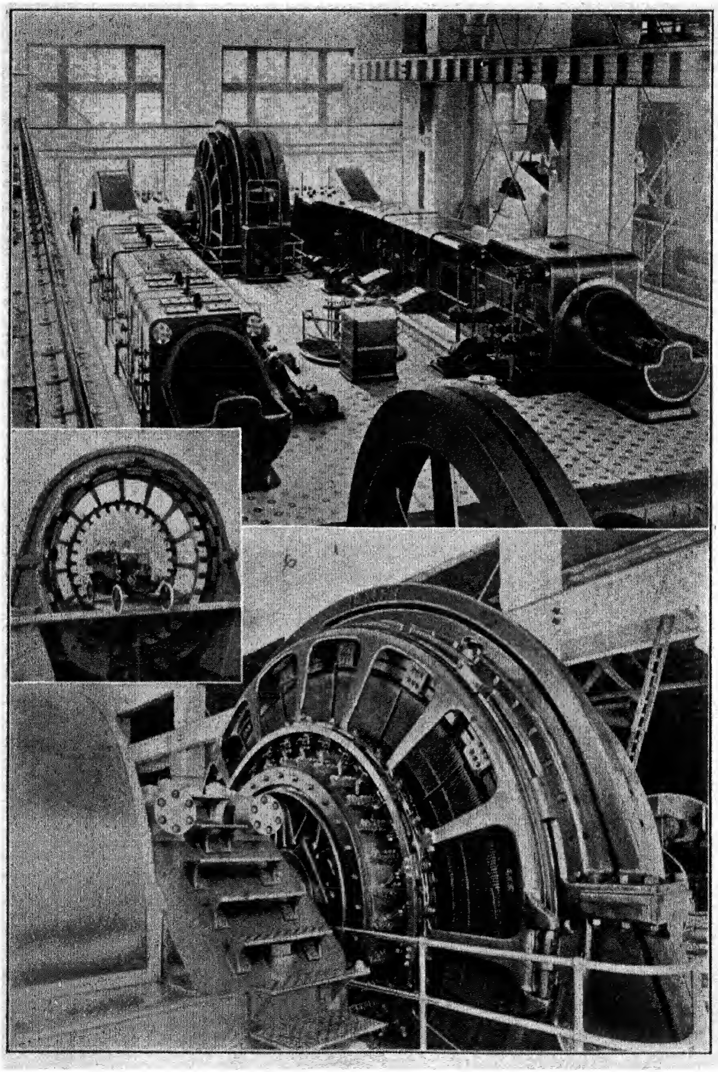
One other fact about the dynamo must be mentioned. At the same time the engine turns the armature and induces a current, the armature is constantly endeavoring to run backward as a motor. This is called the "motor-effect" of a dynamo, and upon the extent of it depends the amount of work that the engine must do. The magnitude of this effect will depend upon the quantity of current that is

being drawn from the dynamo. The greater this is the harder the engine must work. When no current is being taken and the dynamo is generating nothing but voltage, practically no work is required of the engine, but as the amperes and watts increase the demand upon the engine is correspondingly increased.

For high voltages and long distance transmission huge alternators are used, but where low voltages are required for nearby use direct current generators are preferable and for much work direct current is indispensable.

The Electric Motor.—It was early found that if current were passed into the armature of a dynamo it would run backwards as a motor. A motor is essentially a reversed dynamo. The motors that drive the submarines, when submerged, are run as dynamos by the Diesel engines when lying on the surface and are used to charge the storage cells. As a motor the magnetic field of the field magnets reacts on the field of the armature and the latter is made to rotate. Not until the modern dynamo had been perfected, however, was a practical motor possible.

One of the first applications of the electric motor was for street railway traction. The first of these roads was a 1,000 foot "electrical merry-go-round" set up in Berlin at the Industrial Exposition held there in 1879. But it is to Edison that the world is indebted for the real perfection of the electric motor. He showed the necessity for a starting resistance and developed the modern street car controller. In his early experimenting with electric locomotives he found that the sudden rush of current through the armature would burn out the winding before the armature could get started. Therefore he introduced resistance in series with the armature, which was gradually cut out as the motor gained speed. To understand the necessity



View of generators and engines in the Ford power plant.

direct-connected to their shafts. The water used in cooling their hot parts leaves the engine at a temperature of 175° Fahr. and is used for boiler feed and hot-water factory supply. The hot exhaust gases maintain the temperature of the steam between the high and low pressure cylinders of the steam engines, after which they pre-heat the boiler feed water.

The steam units are of the double expansion Corliss type. In the boilers which supply them are 1,800 tubes having a heating surface of approximately 26,000 square feet, and when all fourteen boilers are in operation they consume 2,000 tons of coal and evaporate 22,000 tons of water during each 24 hours. Three thousand gallons of lubricating oil are handled per hour by the filters which supply the engines and dynamos.

The switch board which controls this electrical system is 424 feet long and contains 222 dark Tennessee marble panels. Its cost was $400,000, or nearly $1,000 per running foot. Approximately 165 tons of copper were used in its construction and at present prices would be worth about $100,000 in the raw state.

The whole power plant is controlled by an elaborate signal system which insures continuous service at all times. A 200-pair telephone switch board connects with engine-operating stands, boiler rooms and every distribution center in the plant. In the office is a signal panel carrying 300 signal lamps and a duplicate set of telephone terminals. A green lamp lights on this panel when a feeder is in service and is replaced by a red lamp when out of operation. Thus any trouble in the system is easily located.

This plant is a marvel of engineering design and construction and a monument to American enterprise.

The Niagara Plant.—For nearly twenty-five years a

small portion of the energy of Niagara Falls has been utilized for the production of electrical power and there has grown up about the great waterfall one of the largest and busiest industrial centers of the world. Here those electro-chemical processes which were discovered and first employed by Sir Humphrey Davy find their greatest development in a large number of varied and complex chemical industries. Could this brilliant chemist of more than a century ago visit these wonderful plants and observe, on the enormous scale there displayed, the practical operation of the processes created by his own genius, how completely he would see his dreams fulfilled.

These power plants that dot the brink of the Niagara River generate alternating current and have a total capacity greater than that of any other similar combination of plants in the world. In all, six or seven hundred thousand horse power of electric energy are here developed. But before this energy of Niagara's waters could be utilized the high voltage alternating current dynamo and the transformer had to be perfected. Within little more than ten years from the coming of the first successful commercial dynamos ground was broken for the first Niagara power plant. Marvelous progress had been made in this short period. Electric machinery had been brought to a point such that the "harnessing of Niagara" might cease to be a dream and become a fact.

About a mile above the Falls a canal leads a few hundred yards back from the river and on its banks on either side stand the power houses of one of the main stations of the Niagara Falls Power Company. Beneath each power house is a series of penstocks connected with the water in the canal and having a sheer drop of 180 feet. At the bottom of each penstock is placed a turbine water wheel

which utilizes the kinetic energy in the falling water and passes the spent water into a tunnel running beneath the city of Niagara Falls and emptying into the river just below the suspension bridge. There are 11 of these in one power house and 10 in the other. From each turbine there extends a shaft into the power house above, which carries at the top a generator having a capacity of 5,500 horse power. In the power houses on the Canadian side these generators develop as high as 12,500 horse power. They make 250 revolutions per minute and generate electrical pressures of 2,200 volts on the American side and 12,000 volts on the Canadian side. Like huge tops, day and night, unceasingly, without vibration and with little sound these dynamos spin.

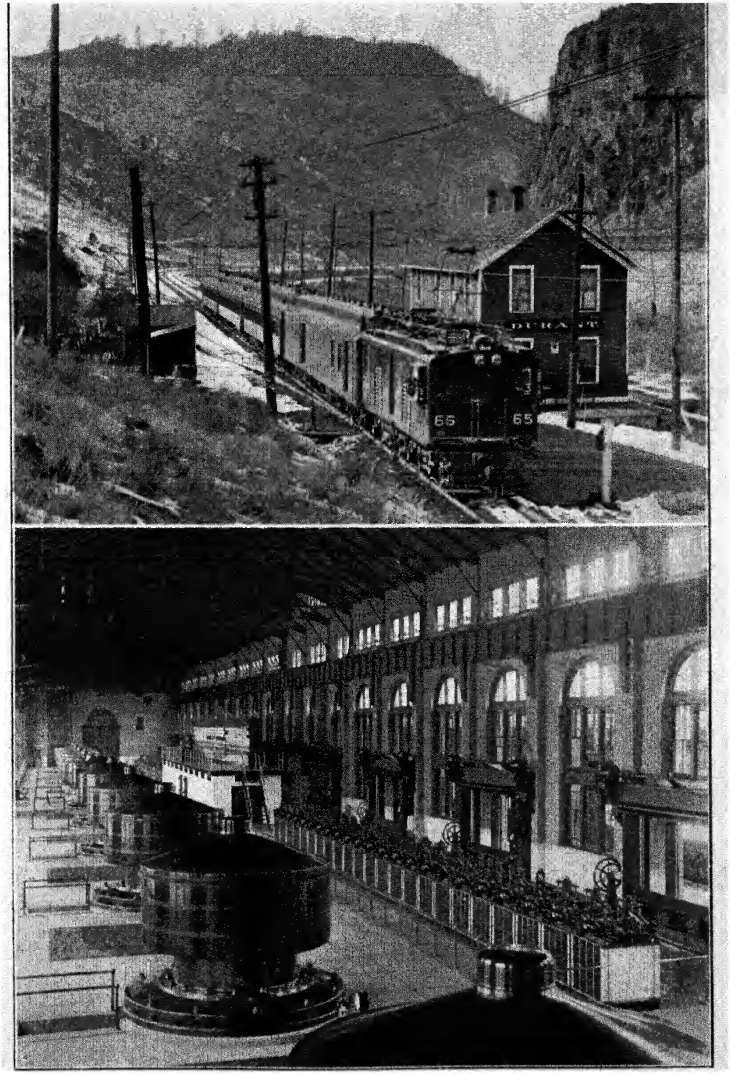
A part of the immense amount of power generated is put through step-down transformers and converters for use in the multitude of factories clustered about the Falls. The rest is stepped up to high tension currents of 60,000 volts in some cases and transmitted to distant cities. The street cars of Buffalo are run with power from Niagara Falls and its streets are lighted with energy from the same source. For long distance transmission high voltages and small amperages make possible the use of much smaller wires, saving enormously in copper, and also reduce many times the heat losses in forcing currents through the line. Where this power is to be used it is stepped down to small voltage and large quantity suitable for motors and lighting purposes.

Waste Water Power.—The conversion of the waste water power of the country into electrical energy for running our mills and street cars and lighting and heating our homes is one of the most urgent problems of the present century. There are going to waste on government lands in the

United States a continuous flow of 28,000,000 horse power. To produce this same amount of power by burning coal would require 390,000,000 tons per year, or two-thirds of the total output. In addition to the waste water power on government lands there are large quantities under private ownership also unutilized. With the constantly increasing demands for fuel and its growing scarcity self-interest and necessity will compel action in the near future. A water fall is not essential to the development of power. Any stream with any considerable volume of water and a strong current possesses energy readily available. Before this century passes a tremendous expansion in the development and utilization of electric power is bound to come. The age of the dreamer and the inventor is yet here, and still greater triumphs lie just beyond the veil that separates the present from the future.

A Great Achievement in Railway Electrification.—One of the most remarkable triumphs of Rocky Mountain railroading is the electrification of 440 miles of the Chicago, Milwaukee and St. Paul lines. This division including some of the most rugged and formidable mountain scenery of the West was electrified and put into operation in 1915. Forty-two giant locomotives, the mightiest of any type in the world, are employed upon it. Each locomotive weighs 284 tons and is driven by eight massive 420-horse power motors, making a total motive force of 3,440 horse power. These motors are run by direct current at a pressure of 3,000 volts fed into them through controlling devices of great complexity.

The power for these locomotives is supplied by the Montana Power Company, located on the Missouri River at Great Falls, Montana. At this point for a space of eight miles the river drops 400 feet, one-half of the drop being



Electric locomotive and passenger train on the Chicago, Milwaukee and St. Paul Railway, and power house of the Niagara Falls Power Company.

an abrupt descent. A total of 139,000 horse power is developed here, a part of which is sold to the Chicago, Milwaukee and St. Paul Railway. Still larger outputs are in process of development and more miles of the road will be electrified in the near future. This power is passed to the sub-stations along the line as alternating current at pressures of 100,000 volts. In these stations it is stepped down to 2,300 volts and converted into direct current at 3,000 volts pressure for use in the motors.

Probably the most unique feature of these locomotives is their system of "regenerative braking." Ordinarily this must be accomplished by air pressure and brake-shoe friction, but in this system no brakes are employed. Reference has already been made to the fact that a reversed dynamo is a motor and a reversed motor is a dynamo. Therefore, when an electric-drawn train comes to a down-grade the power is shut off, and the motors being turned as dynamos by the energy of the descending train develop electric power which is returned to the line, and in so doing the speed is restricted within the limits of safety. The train is made to do work, and the faster it goes the more work it must do. The capacity of these reversed motors is so great that excessive speeds are impossible. The power returned to the line is used to run other locomotives along the division, and any in excess of this is passed through meters of the Montana Power Company and is automatically placed to the railroad company's credit.

These locomotives are used for both passenger and freight service. Very much heavier trains can be hauled and greater speeds obtained than are possible with steam locomotion. Wherever possible electric traction is destined to be the locomotive power of the future.

Since those first simple electrical experiments of more

than two centuries ago to the mighty achievements of to-day a long road has been traveled. Very slowly at first but in recent years with tremendous swiftness, this mysterious manifestation of energy has been mastered and made tributary to the needs of the world. The lightning of Franklin and the electricity of Volta and Faraday have been requisitioned for the service of mankind. The first real sovereignty of Nature began with the mastery of electricity.

CHAPTER XV

THE EVOLUTION OF ARTIFICIAL ILLUMINATION

From the foul smelling, smoke-producing oil lamps of the ancients to the tallow candle of a century ago and the great "White Ways" of to-day, stretches a long pathway of scientific discovery and invention. Night has literally been turned into day and the dazzling brilliancy of gas and electric methods of illumination are to be counted among the crowning glories of modern inventive genius. What the flower is to the plant so is artificial illumination to the scientific discoveries back of it.

Practically all of the epoch-making progress in artificial lighting has come about in the last forty years. In the days of Cæsar and for long centuries after, the king's palace and the peasant's hut, alike, were lighted with a crude sort of lamp—little more than a vessel filled with oil into which was dipped a wick. So sluggish was the progress in all things practical that for centuries nothing better was demanded. And then toward the close of the twelfth century came the tallow candle, which was as much of an improvement over the ancient oil lamp as the electric light is over the candle. The candle was smokeless and odorless. It burned with "great brilliancy" and for the first time in history the world was "well lighted."

The improved oil lamp in Europe dates from the time of the French Revolution. Only animal and vegetable oils were burned in it, for mineral oils were but little known.

In this country, not until after the discovery of petroleum in 1859 were lamps used to any extent. In the pioneer's cabin the pine torch or more often the open fireplace afforded the only light. In the more thickly settled portions the tallow candle held sway until long after the middle of the century. But with the discovery of petroleum and the perfection of methods for refining it came the new era of the kerosene lamp—still widely used in village and farmhouse.

Davy early in the century had demonstrated the possibility of the electric arc lamp, rivaling in brilliancy the light of the sun. But in those days batteries were the only source of current and such an expensive method was impossible. Nevertheless, numerous experimenters continued to devise more or less successful electric lights for half a century. Not, however, until Faraday in 1831 discovered the principle of the dynamo, did electric lighting become commercially practicable. Even then, nearly forty years passed before the invention of a successful dynamo. But in the meantime the very great improvement in battery construction had made possible electric lighting for exhibition purposes. The first electric light was used in France in 1849 during the production of an opera in which it was desired to have the sun appear. When in 1868 the Gramme Ring dynamo was invented commercial currents were available and success assured.

The first electric light to be widely adopted was the "Jablochkoff candle" invented by a Russian in 1876. It consisted of two carbons placed side by side in a vertical position and insulated from each other below. The tips of the carbons were joined by a thin strip of carbon to start the arc, but this almost immediately burned away. As the dynamos then in use produced only alternating current the

two carbons burned off together. This arc lamp gave a very satisfactory light and gained at once a tremendous popularity. It was quickly introduced into almost every region of the world including countries in South America and Asia. For street lighting the arc lamp was unexcelled. The automatic feed and cut out, the glass inclosed arc and improved methods of manufacturing carbons quickly followed.

Edison and the Incandescent Lamp.—Still the small electric lamp for home and office had not come. But the man possessed of the indefatigable industry, the patience and the genius necessary for its perfection was at work in his laboratory. Thomas A. Edison at Menlo Park, New Jersey, set himself to produce a lamp that combining efficiency and cheapness with simplicity and utility should be suitable for universal use. This was in 1878. Very early in his experimenting he gave up the idea of an arc lamp and became convinced that a filament which should be heated to incandescence by its own resistance to the electric current offered the proper solution. But how to get such a filament was the problem. All lamps of this type had been unsuccessful. The filaments burned out almost immediately and other scientists declared the thing "impossible." But it is the mark of genius to accomplish the impossible and Edison, though not recognized as such then, was a genius.

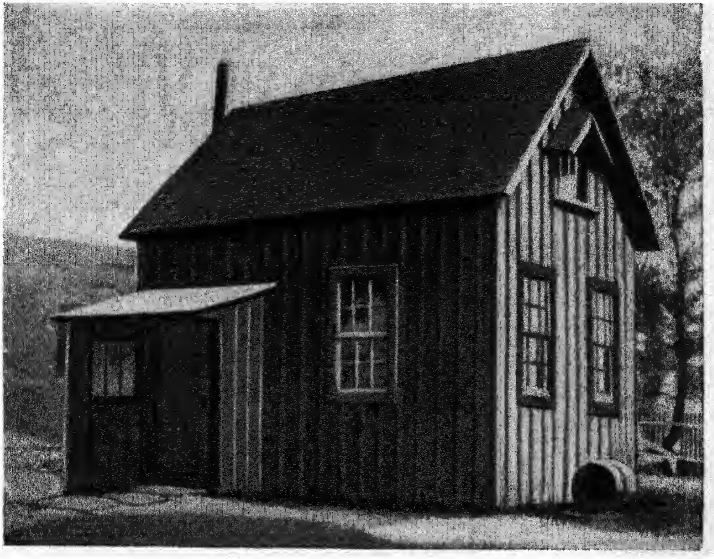
Edison's first experiments were with fine platinum filaments, but platinum was expensive and proved unsatisfactory. He then turned to carbon as the ideal substance for his purpose. On October 21, 1879, after many trials he mounted a carbonized sewing thread in a glass globe from which he exhausted the air. Upon passing a current through this filament it lighted to brilliant incandescence

and continued to glow brightly for more than forty hours. The carbon filament lamp was a success, and one more step had been taken toward "the banishment of night."

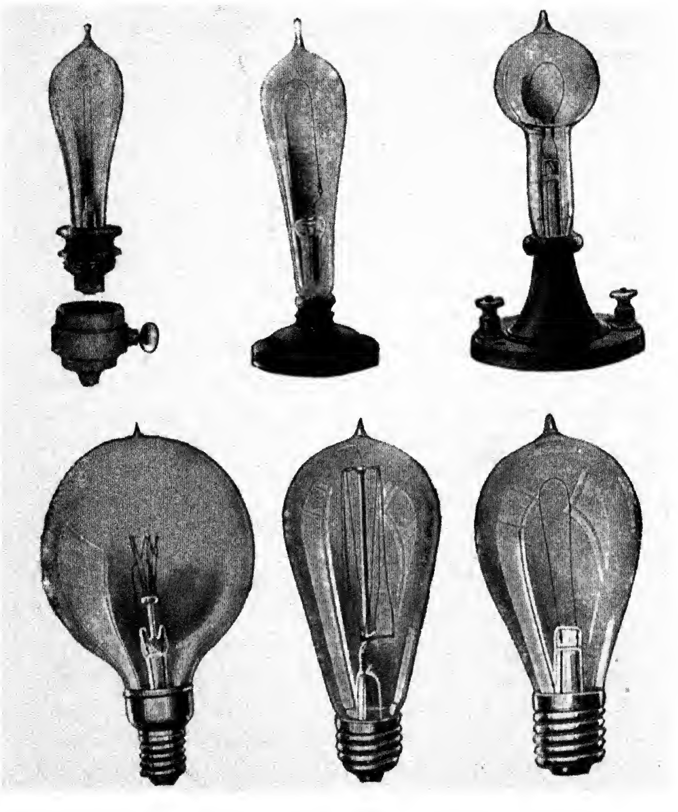
But the carbon filament was only in its infancy and far from perfection. Edison set his assistants to carbonizing every organic substance imaginable in the hope of finding an ideal filament. Carbonized paper proved better than thread. It was cut into the shape of a horseshoe and heated under pressure, out of contact with the air. In less than a month several hundred of these paper filament lamps had been made and put into actual use in the laboratory and in the streets and residences at Menlo Park. Excitement ran high. On New Year's Eve, 1879, special trains were run from New York and nearby cities to witness a public exhibition of the new lamps. More than three thousand persons availed themselves of the opportunity.

Still Edison was not satisfied with the paper filament lamp and the search for a better substance was continued. One day he observed a palm-leaf fan lying on his laboratory table. He was impressed with the long fibrous filaments in its rim and handed it to an assistant with instructions to carbonize them. The result was more satisfactory than anything else that had been tried and Edison sent a man to Japan to find the best variety of bamboo fiber. But he did not stop there. Men were sent to ransack the earth for a better natural product, and at last from the wilderness of the Amazon the ideal material was brought back. It is said that the search for this fiber cost nearly $100,000. But when the man of genius sets to work no obstacle can impede his progress.

Later the plan was adopted of dissolving cotton wool in zinc chloride solution and squirting it through a small hole



Laboratory at Menlo Park where Edison made his first electric lamp.



A few of the types from the paper filament lamp to the nitrogen-filled bulb.

into a tank of alcohol. This formed an elastic filament which hardened in the alcohol and when carbonized proved superior to the bamboo fiber. Such lamps consumed about 3.5 watts per candle power and had an average life of 1,000 hours. The lamp itself underwent a gradual evolution in form of globe and shape of filament. Some of these forms are shown in accompanying cuts.

A metallized filament lamp, called the gem, which reduced the watts per candle power to 2.5 appeared in 1905. In the following year the tantalum lamp, the filament of which was made from the rare earth metal of that name, came on the market but was quickly superseded by the more efficient tungsten lamp. This was in 1907. Six years later in the Research Laboratories of the General Electric Company, it was found that an inert gas like nitrogen placed in the globe of a tungsten lamp would increase several times the candle power per watt and give a light of great brilliancy. The world is now familiar with the nitrogen-filled bulb, giving an efficiency of more than one candle power per watt.

Such in brief is the story of the incandescent lamp which has done more to dispel the darkness of the earth and usher in the "sunshine" than any other invention in all history.

Gas Lighting.—The improved electric light, however, was not to enjoy a monopoly of the field of artificial illumination. For nearly a century the open gas flame had been a strong competitor of the candle and the oil lamp. Then early in the eighties, as a result of research work by Dr. Carl von Welsbach on the rare earth metals, the incandescent gas mantle was invented and the rejuvenated gas light at once became a strenuous rival of the infant electric lamp.

Dr. von Welsbach was examining the rare earth metals

with the spectroscope. To do this it was necessary to raise them to a state of incandescence. One day the idea occurred to him that he might increase this incandescence by saturating a piece of cotton cloth with a solution of the metals and burning it in a Bunsen flame. The idea was immediately put into execution and not only was the incandescence increased but the cotton fiber burned away, leaving a skeleton of metallic oxides which continued to glow with great brilliancy. At once Welsbach conceived another idea, that of a gas mantle to be made by saturating a cotton fabric with solutions of these metals and, when the organic matter had been burned away, to allow a gas flame to play over its surface. In the work that followed he found that the oxide of thorium gave the most satisfactory results. He also discovered that the more pure the oxide was the less light it gave. Evidently the brilliant light-giving properties were due in part at least to the presence of some other substance. Investigation revealed traces of the oxide of cerium, another rare earth metal. But as the result of a prodigious amount of research it was found that only one per cent of this oxide was required. At last the gas mantle formula was given to the world, and it proved the salvation of an industry that with the tallow candle and the oil lamp seemed destined to become obsolete.

These gas mantles are made by fashioning "stockings" from a special quality of cotton fabric and saturating them in a solution of the nitrates of these rare earth metals. These are slipped over a glass form to dry. A loop at the top with which to suspend the mantle over the burner is made from asbestos fiber. When dry a flame is applied which burns away the cotton and changes the nitrates into oxides. This leaves the skeleton in a very delicate con-

dition, too fragile for shipment. To strengthen it the mantle is dipped into a mixture of copal, shellac, alcohol, ether and camphor or often into a mixture of collodion and castor oil. When hung over a burner and first lighted it is this mixture that burns away.

This is simply one of the numerous instances in which the research chemist has made discoveries, very often accidental, which have proved to be of tremendous commercial importance. It is the trained chemist who is able to do original research that can solve the big problems of industry and will command the large salaries paid to men of science.

The Acetylene Light.—In the last decade of the nineteenth century in the very high temperature of the electric furnace, a compound was formed which united directly with water to give a gas of high candle power and a beautiful white light more closely approaching sunlight than any other light known. The substance was calcium carbide and the gas acteylene, both now very familiar to the public. The carbide is made by heating together lime and coke. At the high temperature of the electric furnace the coke, which is almost pure carbon, not only unites with the oxygen of the lime to form the gas carbon monoxide but also combines chemically with the calcium, leaving a dark brown substance called calcium carbide. So unstable is this carbide that water readily attacks it with the production of acetylene gas, and slaked lime.

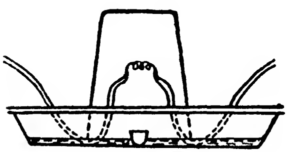
The gas has a very disagreeable fish-like odor and is highly explosive when mixed with air. Many accidents occurred in the early days of acetylene lighting, but generators have been devised which eliminate all danger and the plants now manufactured for country districts have proved a boon to farms and villages not served by gas and electric

companies. The cost of operation is exceedingly low, and this, combined with the soft white light emitted by the burning gas, has made the acetylene lighting system a very strong competitor of the private electric plant for country and suburban use.

EXPERIMENTS WITH ELECTRIC LIGHTING

1. To show the necessity for exhausting the air from the globe of an incandescent lamp, select an old lamp and with a pair of pliers carefully break off the tip. Now make a tiny hole at this point and let in the air. Then screw the lamp into a socket and turn on the current. It will flash up brilliantly and then go out, the filament having been burned away at one or several points. This is due to the oxygen in the globe.

2. Between the binding post of the asbestos covered board made in Experiment 3 under the Heating and Chemical Effects of the current, place a piece of No. 30 iron wire. Connect this with a dozen dry cells or in series with the rheostat and house current. The wire will be heated to incandescence for a few moments and then burn away.



ELECTRIC LAMP

Fig. 94.

3. But if the wire in the previous experiment could be placed in a vacuum or in air from which the oxygen had been removed it would continue to glow for a long while. To remove the oxygen, invert a drinking glass over water in a shallow dish as shown in Fig. 94. Cover the copper lead wires passing underneath its edges with small rubber tubing to insulate them from the water and bend them up-

ward, leaving a small gap at the top for the filament. On the surface of the water, float a small crucible containing a little alcohol. Insert a filament of fine iron wire and light the alcohol with a match. Immediately cover the crucible and filament with the inverted tumbler and wait for the flame to disappear. The burning alcohol will remove the

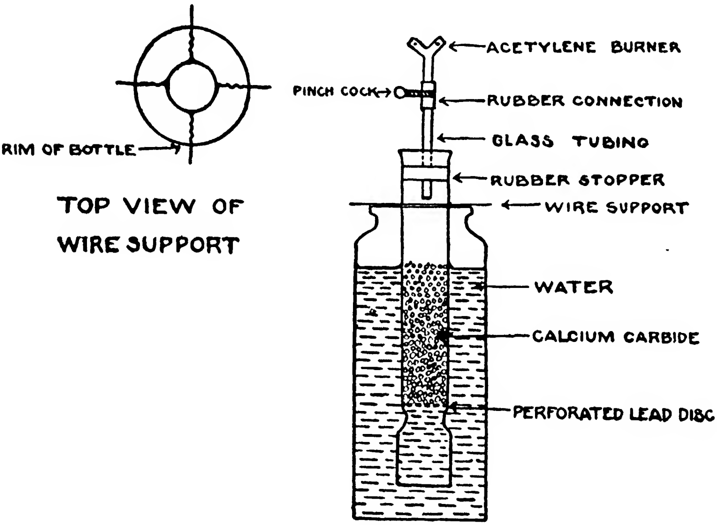


FIG. 95.—Acetylene lamp.

oxygen from the air under the tumbler. Now connect the copper lead wires with cells or the house current and rheostat. The filament will light up and continue to glow indefinitely provided the oxygen has all been removed.

German silver wire may be substituted for iron, and perhaps you can insert a very fine splinter of willow charcoal.

Homemade Acetylene Lamp.—A very simple form of

acetylene lamp can be easily made by anyone from the following materials:

A large-mouthed bottle of one to two quarts capacity, a lamp chimney, small lead disk, one-holed rubber stopper, 6 inch piece of glass tubing, rubber connection, acetylene gas tip and 18 inches of aluminum or other heavy wire.

Put the apparatus together as shown in the diagram. The lead disk may be perforated with a hammer and nail punch. Then fill the lamp chimney two-thirds full of lumps of calcium carbide and pour water in the bottle. Open the pinch cock and the water will rise through the lead disk and coming in contact with the carbide will generate the acetylene which in a few moments may be lighted at the burner.

The wire support may be made by placing two sets of aluminum wire about the chinmey at right angles to each other and twisting the ends together with pliers.

When once charged the lamp will give a good light for a considerable period and will be found useful in workshops and wherever gas or electricity are unavailable. To recharge, remove the stopper, clean out the chimney and refill with carbide. The higher the water in the bottle the greater the gas pressure.

Chapter XVI

FIRE AND HIGH TEMPERATURES

The superiority of primitive man to the wild beasts about him and the first great step toward the conquest of nature must have been demonstrated in his mastery of fire. Not until that time arrived could he have been very far removed from the man-like animals from which he had descended. Very early the phenomenon of fire must have attracted his notice. The volcanic eruption, the lightning flash or, perhaps, the rubbing together of two dry branches in a strong wind very frequently kindled fires. Appealing at first, doubtless, only to his superstition, the grateful warmth of these fires added to his sense of comfort and aroused a desire to perpetuate them. By their aid he cooked his food, fashioned his implements and lighted his cave. But for how many centuries this use of fire extended only to a knowledge of the means of feeding and perpetuating it, we do not know. When, however, either by the rubbing together of two dry sticks or by the chance spark from a flint and steel, he learned to kindle a fire himself, his first real mastery of it began. The camp fire before his open cave lured wild animals within his range. With its aid he dried and toughened the wood which he shaped into formidable instruments of warfare. Very gradually through his experiences with fire he acquired a rudimentary knowledge of the arts of pottery, glass making and the metallurgy of the simple ores.

And so it has been from the time of the cave dweller to

the present day. Just as man's knowledge of fire—its origin, its explanation and applications have expanded, so has his proficiency in the arts and industries grown. There is scarcely an article that ministers to our physical comfort which has not somewhere come under the influence of fire. From the village forge to the steel mill and throughout the wide range of manufactures, fire is a fundamental requisite of success. When fuel cannot be had, factories close, locomotives cease to run, our streets and houses are in darkness, and industry in general is at a standstill. Not only is fire essential to all industrial progress, but high temperatures are equally important. With each advance in the degree of heat obtainable in our furnaces, have come additional triumphs of science and new commercial processes. The alchemist in his vain endeavor to transmute the baser metals into gold, knew no higher temperature than that possible with good beech wood. Then came coal and gas with the forced draft, to be followed by the oxy-hydrogen blowpipe, the electric furnace, thermit, the oxy-acetylene torch and the explosion of cordite. Temperatures now rivaling those of the sun are within our grasp and subject to our control.

The oxy-hydrogen blowpipe for many years represented the acme of high temperature attainment. Not very long ago its use for the production of the "limelight" in the stereopticon was very common. Large pressure tanks containing oxygen and either hydrogen or coal gas were connected to an especially constructed blowpipe having a tube through the center for the passage of the oxygen and surrounded with a jacket for the hydrogen. The gases mixed in proper proportions at the nozzle and burned with a temperature of about 2000° Centegrade. When this flame was played over a stick of quicklime, the lime was

heated to a brilliant incandescence and was formerly the only method of producing a strong light for stage and lantern projection. This flame, too, was used for glass working, for making artificial gems, for melting platinum and wherever the "highest" temperatures were required. And then toward the close of the last century came the electric light with its greater efficiency, higher power and extreme simplicity and convenience. The limelight went the way of the candle and the oil lamp, and the oxy-hydrogen flame was retained only for minor operations.

Professor Henri Moissan of Paris did the first important work with the electric furnace and in a series of researches now classic this brilliant French chemist produced a large number of carbides of both the metals and the non-metals. A carbide is a compound of carbon and another element, of which carborundum and calcium carbide are the two most common examples. His crowning achievement, however, was the production of artificial diamonds. A diamond is simply crystallized carbon. Moissan knew that small diamonds are sometimes found in meteoric iron which bears evidences of having been subjected to great heat and probably high pressures. It therefore occurred to him that possibly carbon dissolved in molten iron and then plunged into cold water would also crystallize into a genuine diamond. Accordingly he placed a mixture of charcoal and iron in a carbon crucible and covered it up in his electric furnace. After about six minutes he removed the crucible containing the molten iron and dissolved carbon with a pair of tongs and plunged it into a tank of water. A great boiling and seething followed but no explosion. The iron solidified, subjecting the carbon to tremendous pressure, and when the mass was treated with strong acids and other chemicals the residue showed the

presence of microscopic diamonds. The thing had been done, and it only remains for some other chemist to make diamonds of commercial size.

The furnace employed by Moissan was of the arc type and consisted of two fire bricks placed one on top of the other. On either side was a groove for the carbon electrode and in the center a cavity for the crucible. The cover brick was hollowed out slightly to increase the size of the cavity and to reflect the heat of the arc back into the crucible. The arc was identical with that produced by Davy nearly a century before and gave a temperature close to 4000° Centegrade.

One of the first applications of the electric furnace in a commercial process was by Dr. Edward G. Acheson in the production of *carborundum.* Carborundum is the stuff with which the dentist drills the cavities in your teeth and one of the greatest artificial abrasives known. Back in 1891 Dr. Acheson was looking for a material which would be superior to emery for grinding purposes. For his furnace he used an ordinary plumber's bowl which he filled with a mixture of coke and clay. One of the wires from his dynamo he connected to the bowl and the other was thrust into the mixture. When he turned on the current the mass gradually fused, and as he withdrew the wire after a time there were found clinging to it a few very small, sparkling crystals. Cautiously he removed the crystals and picking them up on the point of a pencil drew the pencil across a pane of glass. They readily scratched the glass and Dr. Acheson knew that in these hard, sharp, brilliant diamond-like crystals he had found a new abrasive.

The experiments were continued and, when enough crystals to fill an ounce bottle had been made, Dr. Acheson put them in his pocket and hurried to New York. There

he sold them at 40 cents per karat to a prominent firm of jewel polishers as a substitute for diamond dust. The Carborundum Company was organized and the first plant established at Monongahela, Pa. In the first year 15,000 pounds of carborundum were manufactured. This was in 1893 and two years later because of the great hydro-electric power plant that was being established at Niagara Falls the factory was moved there. Since that time the business of the company has grown until the present plant covers 19 acres of floor space and is equipped to handle continuously 25,000 horse power of electric energy. Upwards of a million and a half pounds of carborundum are manufactured every month.

An analysis showed carborundum to be a compound of carbon and silicon. The furnace charge for its preparation consists of coke, sand, sawdust and common salt. The coke and sand are the essential ingredients, the sawdust being used to make the mass porous and the salt as a purifier. The furnace itself, built of fire brick, is 30 feet long, 12 feet wide and 10 feet high. The mixture is mounded up in the furnace and a resistance core built through the center. At each end are huge cables through which the current is conducted and passed along the core where it generates the very high temperature of the electric furnace. The current flows for 36 hours and during this time enough electric energy is consumed "to operate an arc light continuously day and night for 12 years or to operate one sixteen-candle-power carbon incandescent lamp for 220 years." There are 30 of these furnaces in continuous operation.

At the end of the run the furnace is opened up and huge masses of beautiful carborundum crystals glistening with all the colors of the rainbow are removed. These crystals

are crushed, washed with strong acids and sieved through screens of bolting silk into grits of various sizes. Bonding material is added and the mixture is fashioned into grinding stones and wheels of all shapes and sizes, but this process is another story. These stones are good for grinding everything from jewels and teeth to railroad iron and armor plate.

Here, too, in the Acheson plant artificial graphite excelling the natural product of the mines is manufactured in the intense heat of the electric furnace.

Another electric furnace product manufactured at Niagara Falls and Worcester, Mass., is *Alundum.* This is the trade name of an artificial emery made by fusing aluminum oxide and rivals carborundum as an abrasive. Under the influence of the electric furnace a large variety of other alundum products are manufactured for use in chemical laboratories and high temperature industries. Crucibles, combustion tubes and resistance furnace cores, unaffected by the most sudden and violent changes of temperature, have been of immense assistance to the chemist. Such ware may be heated white hot and plunged into ice water without breaking.

The electric furnace is used, too, for the manufacture of calcium carbide, the fertilizer calcium cyanamide, and for the highly important process of getting nitric acid from the air. Electric furnaces are employed in the metallurgy of steel, and a host of chemical industries depend for their success upon the high temperatures which electric energy will produce.

One more application of the arc must be mentioned and that is in *electric welding.* The art of welding is as old as the working of metals itself. At Delhi, India, stands an iron shaft 16 inches in diameter, extending 22 feet above

the ground and 40 feet below which shows a hand-forged weld as perfect as any that could be made with the most modern process and equipment. And this shaft is nearly two thousand years old. The electric-arc welding process as applied to broken street car rails is a frequent sight on our city streets. In the Slavianoff system, the most important of arc welding processes, a metallic pencil serves as the negative electrode and the metal to be worked as the positive. One of the lead wires is joined to the pencil and the other to the metal to be welded. An arc is struck by bringing the two electrodes together and then quickly separating them. In the intense heat of the arc the metal melts and runs together into a solid mass. Sometimes filling-in metal is inserted between the broken ends. A protection from the fierce heat and blinding light must be worn by the operator and great skill exercised in the manipulation of the arc. In many of the recently constructed shipyards no other welding process is employed.

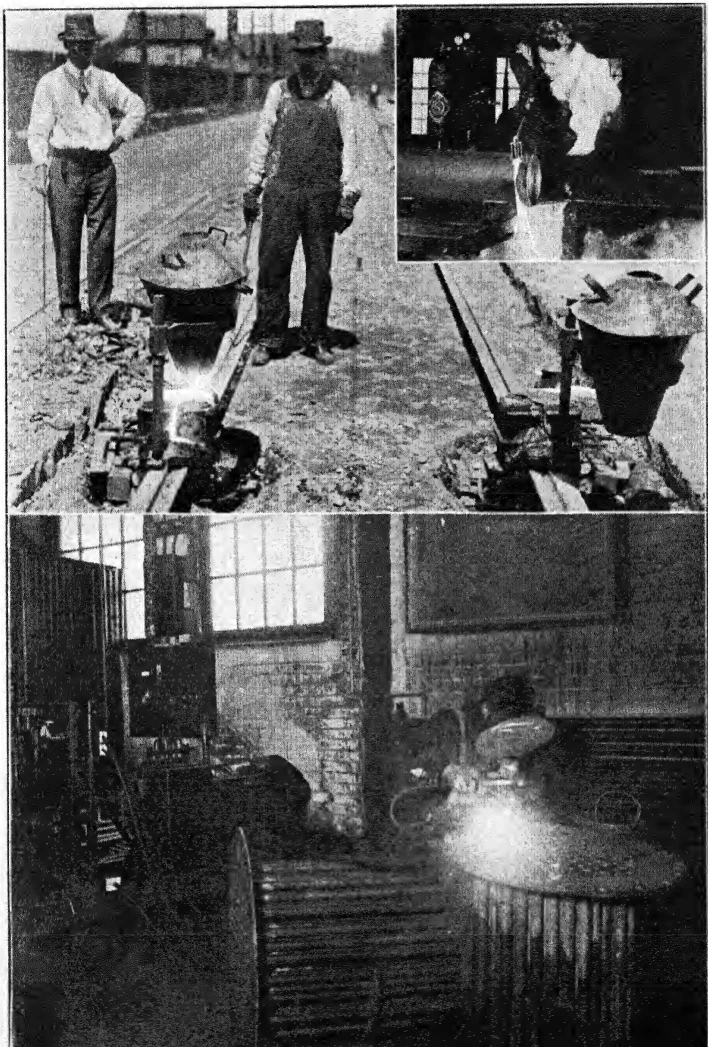
Oxy-acetylene Welding.—Another commercial process which must be credited to recent progress in high temperature research is that of oxy-acetylene welding. When acetylene gas is burned in a blowpipe similar in construction to the oxy-hydrogen blowpipe a flame results whose temperature is very close to that of the electric furnace. With a torch of such temperature it at once became possible to weld the more difficultly fusible metals simply by melting them together. By this process metals of almost any kind can be welded, and wrought iron and steel can be cut with the utmost ease and perfection. If the metals are thin their edges are brought into contact at every point and then by application of the torch fused together. In other cases a space is left between the metals to be joined and the operator holding the torch in one hand and a stick of the same

kind of metal in the other, fuses it and runs it into the space. Previously to doing this, however, the metals to be welded are pre-heated so as to shorten the process and eliminate strains when the weld has cooled.

This process has a large number of applications. It is especially adapted to repair work of all sorts. Steel tanks can be welded instead of riveted. It is employed on refrigerating pipes, safes, steel office furniture, bicycle frames, aluminum ware, automobile parts and the results are permanent and highly satisfactory. In a skating rink in San Francisco more than ten thousand joints and ten miles of brine pipes were welded recently by the oxy-acetylene process.

But it is in the cutting of wrought iron and steel that the oxy-acetylene torch has had its most interesting application. An especially constructed torch pre-heats the metal to be cut to a temperature of about 1000° C. by a number of small oxy-acetylene jets and then a jet of oxygen at high pressure is turned on. This oxidizes the hot metal and the force of the jet carries away the molten oxide as fast as it forms. Old armor plate that was formerly cut by the most laborious processes requiring weeks of time is now cut in little more than as many hours. Steel up to 30 inches in thickness is readily cut. In one instance a gun-turret top was cut at a cost of $54.38 which by the old method of drilling holes and breaking would have cost $2,000.

It should be borne in mind, too, that these processes which save not only time and money but make possible scores of new achievements are the results of scientific research. It is to men like Davy, Faraday, Moissan and Edison, only to mention a few, that the world owes its marvelous material progress of to-day and recent years.



Oxy-actylene, thermit and electric welding.

Thermit Welding.—Still another source of high temperatures and a process of very great commercial importance must claim our attention before we leave this subject.

Go into the locomotive repair shops of any great railway terminal and there you will find men wearing large, colored glasses at work tapping white hot molten steel at a temperature of 5000° Fahrenheit from a conical vessel into a sand mold built about the broken parts of some locomotive drive wheel or portion of the frame. These men are employing the "thermit" process of welding and this disabled locomotive will be ready for service within twelve hours from the time it came into the shops. Furthermore, the welded part will be stronger than it was originally. In the "old days" it would have been necessary to remove the broken parts, forge and replace them, necessitating a delay of days and frequently weeks. But not so now, thanks to the marvelous progress of chemical research and invention.

But what is thermit? The name suggests thermal, and the two words have the same basic meaning—heat. And that is the reason for the name, for the temperature generated in this process is among the highest known to science. Soon after the production of pure aluminum and the determination of its properties in 1854, it was discovered that, if this metal were heated with a metallic oxide, a chemical change of explosive violence would take place, liberating immense quantities of heat and blinding light, together with the molten metal at a temperature much higher than its melting point. Regarded at first as an interesting experiment, it remained for Dr. Hans Goldschmidt to give a practical application to this important chemical change.

Just at that time Dr. Goldschmidt was attempting to

produce pure metals to alloy with iron in making various kinds of steel. Knowing this property of aluminum, he decided to make use of it and began to experiment. The explosive violence of the reaction first had to be overcome, and this was accomplished by heating the mixture of aluminum dust and metallic oxide in a single spot until the change began, when it would spread quietly throughout the whole mass, liberating a lake of molten metal as clear and limpid as water in a cup. No one who has never experienced it can have any adequate appreciation of the keen pleasure enjoyed by an investigator who thus carries to a successful termination some piece of research. Dr. Goldschmidt found that practically any metal could be obtained in this way, and among those with which he experimented was iron. The result was the production of the superheated, liquid metal at nearly double the temperature of molten steel. The process required but 40 to 50 seconds for completion, and Dr. Goldschmidt decided that such intense heat, so quickly and easily produced, could be used in many ways for welding purposes. This decision resulted in the "thermit" process, soon so widely known throughout the world.

Thermit itself consists of small, black grains of iron oxide thoroughly mixed with finer grains of aluminum dust. Were it not for the white particles it would have much the same appearance as coarse gunpowder, but no one would ever suspect the vast quantities of wonderful energy latent within. It is shipped in metal drums carefully sealed to exclude moisture, for if it once becomes damp, the thermit is useless and cannot be regenerated by drying. Thermit is perfectly safe to store, for a temperature equal to that of molten steel is required to start the chemical reaction.

In making a thermit weld, the parts to be united are placed with a space between them varying from one-half inch to two or three inches, according to the size of the sections. Wax is then fitted in this space, making a pattern of the exact shape of the reinforcement of the thermit steel, which is to be cast around the parts to make the weld. This wax pattern is enclosed in a sand mold, provision being made for pouring and overflow openings at the top and a small opening at the bottom for preheating the parts to be welded. By means of a compressed air gasoline pre-heater the wax is melted from the mold and the parts brought to a good red, workable heat. In the meantime the requisite charge of thermit is placed in a conical crucible lined with a fireproof clay and the crucible placed over the pouring "gate" of the sand mold. When the sections are red hot the pre-heater is withdrawn, the opening at the bottom plugged up and the thermit charge in the crucible is ignited. In from 40 to 50 seconds the thermit reaction is completed and the thermit steel is tapped from the bottom of the crucible into the mold, where it flows around and between the sections to be welded together, uniting them into one solid mass. The iron being heavy, sinks into the mold and the slag, consisting of aluminum oxide, rises to the top and overflows. A considerable quantity of iron also rises into the pouring and overflow gates and when solidified projects above the welded part as so-called "risers." To ignite the thermit in the crucible requires a very high initial temperature, and to obtain this an especially prepared powder is placed on the thermit, together with the head of a parlor match. When the match is ignited, this powder burns with such intense heat as to start the thermit reaction.

The welded portion is allowed to cool slowly, for this

annealing process removes strains and increases the strength of the weld. The next step is to cut away the risers and machine off the surplus metal. When this has been done, the welded shaft or whatever it may be is not only repaired but is actually stronger than before it was broken. Instead of being a weak spot and source of further trouble, it is in fact an added element of strength.

One of the most extensive uses of thermit is in the marine field for welding broken sternposts, rudder frames, and propeller shafts of steamships. The great economy in this field can easily be understood, from the fact that the average cost to a steamship of lying in dry dock is $1,000 a day, and therefore if a repair can be executed in 48 hours by this process, as against several weeks by the former methods, a tremendous saving is effected. The United States Navy was among the first to appreciate the advantage of the thermit process and has used it very extensively at the New York, Boston, Portsmouth and Charlestown navy yards. In addition, the repair ships *Panther*, *Dixie*, and *Vestal* have complete thermit welding outfits and have done very important work.

Vast quantities of thermit have been used by the Government on the Panama Canal, and the process has been employed for welding and reclaiming broken parts of dredges, dipper buckets, locomotives, rock crushers, rock drills, air compressors and all sorts of machinery used in building the canal.

But one of the most striking and familiar applications of the thermit process has been by street railway companies in welding broken rails and installing permanent joints in place of mechanical joints. Scenes similar to those in the accompanying picture are frequent sights along the street railway lines of any large city.

HIGH TEMPERATURE EXPERIMENTS

1. *A Homemade Electric Furnace.*—An electric furnace of the arc type can very easily be made by any boy from the following materials: fire clay, asbestos fiber and water glass. A mixture of these ingredients will quickly dry and harden into a fireproof mass of low heat conductivity.

To make the furnace, select a box about 8 inches long and 4 inches square. Bore a hole a little above the center of

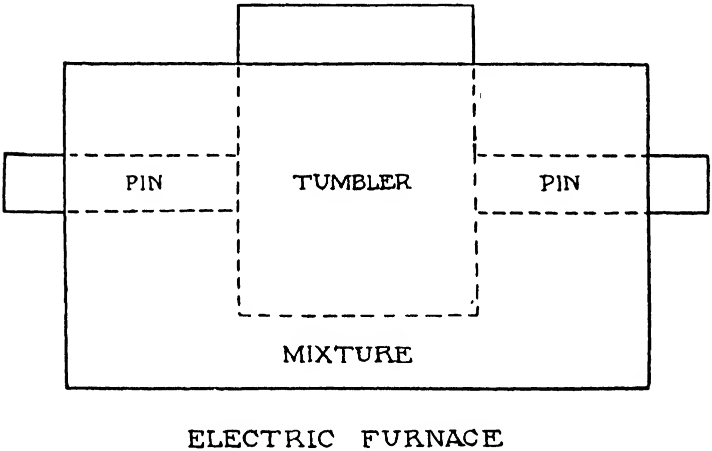


Fig. 96.—Arc furnace.

each end just large enough to take a standard light carbon. Then mix some of the fire clay, asbestos fiber and water glass, in the form of a solution, until a doughy mass is obtained, and pack a layer one inch thick in the bottom of the box, forcing it down as far as possible. Now insert an ordinary glass tumbler in the center of the box and two wooden pins the size of light carbons in the holes at the ends. Around these pack as firmly as possible more of the

mixture, filling the box completely. Smooth off the top and fill in the small cavities with a mixture of fire clay and water glass alone. In similar manner make a cover of the same size about an inch thick. Place the box and contents together with the cover in some warm place, preferably on the top of a furnace, and allow them to dry for about ten days. At the end of that time the box may be broken away and the pins and tumbler removed. To improve its appearance the outside may be retouched with a little fire clay and water glass. The result is a very efficient arc furnace of practically indestructible material which can be used in series with a suitable resistance on any house lighting circuit for many experiments where high temperatures are required. The materials, too, are inexpensive and easy to obtain.

A small carbon crucible containing any substance which it is desired to heat may be placed just beneath the carbons. For this purpose it is a good plan to make the holes for the carbons slanting downward into the cavity.

2. *A Resistance Furnace.*—Another type of furnace owing its heat-producing power to the resistance of a metallic conductor will be found very useful. To make it, secure a corrugated Alundum core 2½ inches deep and 2 inches in diameter. This is hollow and should be closed at one end and open at the other. Now wind as closely as possible 42 feet of No. 20 Nichrome wire on a spindle $^3/_{32}$ of an inch in diameter, leaving one foot free at each end for connections. When it has set stretch the coil slightly so that the turns will not touch, and starting with one end at the center of the grooves on the bottom of the core wind it about the cylinder and secure it in position temporarily with cord. Cover the whole with a layer of Alundum cement to a depth of $^1/_8$ of an inch and connect directly to a 110 volt

lighting circuit. This will very quickly cause the cement to set.

This furnace will give a continuous temperature of 1000° C. For lower temperatures a rheostat must be inserted in series with the furnace.

A cover like that of the arc furnace should be made of

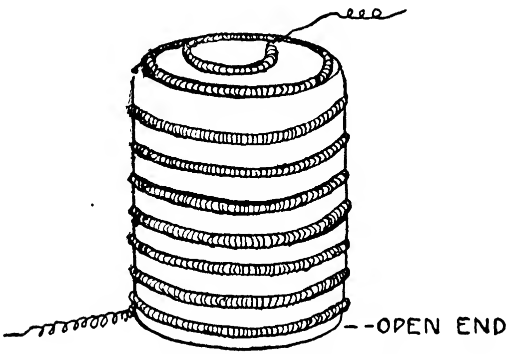


FIG. 97. Resistance furnace.

asbestos fiber, fire clay and water glass. When in use always set the furnace on a square of asbestos cardboard.

3. *Melting Metals.*—In a porcelain crucible place a few pieces of metallic copper and set the crucible in the furnace. Cover and use the full 110 volts of the lighting circuit without the rheostat. Usually the melting point of copper will be reached.

4. *Making Quicklime.*—Place a few lumps of marble in the furnace and heat for 20 or 30 minutes. After the current has been turned off and the product is thoroughly cold remove some of it and sprinkle with a little water. This is

quicklime, and the swelling up and evidences of heat observed are the same as occur in the slaking of lime in a mortar box on the street. Your furnace is a miniature limekiln.

Other uses for the furnace will suggest themselves. If you have a laboratory, for much work it will take the place of a Bunsen burner.

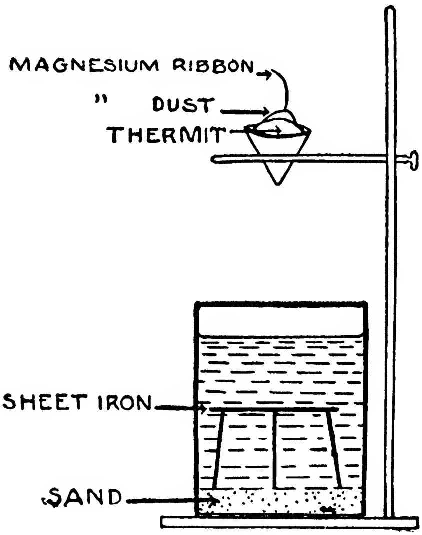


FIG. 98.—Thermit demonstration.

5. *Demonstration with Homemade Thermit.*—A very striking and spectacular demonstration with homemade "thermit" can be carried out by anyone with the following materials and directions:

Mix about equal quantities of aluminum dust and red iron oxide, or ordinary rouge, on a folded paper and place the mixture over a battery jar of water as shown in the

diagram. Prepare the paper by cutting a circular piece about 3½ inches in diameter, folding in half and then folding in half again, when it may be opened up in the form of a hollow cone which will serve as a container for the thermit. At the top of the conical heap of thermit place a little magnesium dust and thrust into it an inch and a half strip of magnesium ribbon. The bottom of the battery jar should contain an inch layer of sand on which place a tripod, or some other support carrying a square of sheet iron. The square of iron may be three or four inches below the surface of the water. Upon touching a match to the magnesium ribbon the whole mass of thermit will quickly ignite and a stream of white hot molten iron will run into the water and striking the sheet iron melt a hole through it. If the demonstration is made in the evening or in a darkened room a very brilliant effect is produced.

The chemical action consists in the union of the aluminum with the oxygen of the iron oxide, liberating the iron and an immense amount of heat energy. This is the same reaction that occurs in the thermit process of welding a broken street car rail.

The ignition powder will work better and more certainly if a little powdered potassium chlorate is mixed with the magnesium dust.

Chapter XVII

SOME NOTABLE ACHIEVEMENTS IN CHEMISTRY

The War of the Nations which at the present moment has been raging for four years, is in its physical and material aspects a tremendous contest between chemical forces. From the poisonous gases, the high explosives, the armor plate and the big guns to the healing drugs of the hospital and the fertilizers for the production of food stuffs, it is all a matter of chemistry. Every volley that sweeps the shell-torn battlefields of Europe is accompanied by a million chemical reactions. And what havoc this mad dance of the atoms and the molecules has wrought. Such violent liberation of pent up chemical energy has at last created the madman's paradise. Even the inventors of explosives have surprised themselves. Before the terrific onslaught of T. N. T. concrete and steel are as chaff in the wind. The fixed fortress has become obsolete. The strongest walls can be reduced to ruins in a few hours. In the volcanic-like breath of a bursting shell a thousand lives may be snuffed out and the adjacent scenery blown to dust. Modern warfare is the product of the man of science. The cannon-fodder on the battlefield is merely a huge mechanism to execute his will and give practical demonstration to the creations of the laboratory. Without Germany's chemists this war would have been over in a few weeks, or months at the most. In fact, it never would have been begun. It is the Krupp steel works, the nitrate-from-the-

air plants, the early monoply of coal tar explosives that the world has had to fight. They afforded the sinews for Germany's murderous attack on the peace of Europe. More to be dreaded than her armies are the scientists in her laboratories. But although the rest of the world was caught napping, the men of science in other nations have demonstrated their ability to specialize in the chemistry of war and beat Germany in her own chosen field.

Explosives.—Since the foundations of the earth are fairly rocking from the liberated energy of high explosives, let us first consider this aspect of modern chemistry. From the black gunpowder of a century ago to the nitrocellulose, picric acid and T. N. T. of present-day warfare, nitric acid has been an essential ingredient of their manufacture. And therefore the matter of explosives comes down to a question of producing in abundance this nitrogen compound. Old-fashioned gunpowder was a mixture of powdered charcoal, sulphur and potassium nitrate, or saltpeter. Napoleon scraped together the saltpeter for his campaigns from caves and decaying compost heaps. But he did not need very much. More nitrates are used in one day's cannonading on the Western Front than Napoleon or Grant used in a whole campaign. Nitrates are salts of nitric acid and essential to the production of the acid. In only one spot on the earth's surface is nitrate salt found in abundance. This is a narrow rainless strip on the western slope of the Andes mountains in northern Chili. These deposits are known to the world as Chili saltpeter. They have been and are yet of immense importance as soil fertilizer and for the manufacture of explosives. For many years they constituted the world's sole supply. Previously to the war they were being exported from Chili at the rate of nearly 2,000,000 tons a year. As one slight preliminary

item of preparation for her great attack, Germany in the year before the war corralled 1,000,000 tons of these salts. She also bought all that were available in the markets of Europe. But when the titanic struggle burst forth even this immense store disappeared like mist before the sun. When it became apparent that Germany had something more on her hands than a brilliant military parade for the overawing of Europe, other means for the manufacture of nitric acid were at once imperative. Her initial supply was only a priming. But Germany was prepared for any emergency. Her chemists had solved this problem before the war was launched. They even announced it to the world at the meeting of the International Congress of Applied Chemistry held in New York in September, 1912. In 1913 Germany was investing millions of dollars in chemical plants for this very purpose. She is now using over 200,000 tons of nitric acid each year and, though cut off from the outside world, her supply is inexhaustible.

Before we take up the present war-time process employed by Germany for making nitric acid we must go very briefly into the history of the "fixation" of atmospheric nitrogen. Nitrogen is a most inactive element. It enters into chemical combination with other elements with great difficulty. And yet it is most essential to life and industry. Not only is it the moving factor in high explosives, but it is also a fundamental ingredient of a complete fertilizer and a constituent of all tissue-building foods. Therefore, when Sir William Crookes in 1898 in his presidential address before the British Association for the Advancement of Science predicted the early exhaustion of the Chili nitrate beds and urged immediate work upon a process for fixing into available compounds the inexhaustible supply of nitrogen in the air, the chemists of the world

got into action. It was also seen that any nation cut off from Chili saltpeter in time of war would be powerless to resist and forced to surrender. Therefore the spur of self-preservation acting from opposite points of the compass prompted widespread and vigorous research on this problem.

The great ocean of atmosphere about us is four-fifths free nitrogen. Upon every square yard of the earth's surface rests approximately seven tons of this element. But how to make it combine with other elements into useful compounds was a baffling problem. The first men to work out a practical solution were two Americans, Bradley and Lovejoy. In 1902 at Niagara Falls they established the first commercial process for the fixation of atmospheric nitrogen by means of the electric arc. They demonstrated the possibility of making nitric acid in paying quantities directly from the air, but both the capitalists and the Government were indifferent and its development passed to other countries. At the same time other investigators were at work and very soon it was announced from Norway that Birkeland and Eyde had also solved the problem. They, too, employed the electric arc, using a high-tension alternating current and water-cooled copper electrodes. Air was passed through this arc and it was placed between the poles of a powerful electro-magnet which blew it out into a flaming disk of burning nitrogen and oxygen. In the intense heat of this arc nitric oxide is formed which unites with more oxygen from the air to form nitrogen peroxide, and this dissolved in water yields a mixture of nitric and nitrous acids. Other processes also employing the electric arc were developed in Germany. Still another process has been perfected whereby in the heat of the electric furnace free nitrogen obtained from

liquid air can be made to combine with calcium carbide and form the highly important fertilizer, calcium cyanamide.

At last the world seemed independent of Chili saltpeter. Millions of dollars and hundreds of thousands of horse power were soon engaged in the profitable business of extracting nitrogen from the air. But there was one drawback to these new-found processes. They depended for their success on vast quantities of cheap electric energy, and this is possible only where there is an abundance of water power. The immense water power in the mountains of Norway made that country especially adapted to the installation of these nitrogen-from-the-air-plants and there they have had their greatest growth. The waterfalls and rivers of Norway have a potential capacity of 200,000,000 horse power, and this region is destined to become one of the greatest industrial centers of the world. Iceland, Africa and America also have great water power, all of which must and will be turned to account. But Germany is lacking in this prime requisite and her coal is needed for other purposes. Therefore in her case some other method for making nitric acid was a necessity.

From the beginning of the coal gas industry a century ago these plants have been busy extracting the ammonia from the gas. Ammonia is another nitrogen compound familiar as a household cleaning agent and characterized by a sharp penetrating action on the nostrils, making it useful in the emergency of a hard cold. Although bought in the form of a liquid, ammonia is a gas and the familiar household variety is the gas dissolved in water. Ammonia is also used for laboratory purposes, for the manufacture of artificial ice and for the production of ammonium sulphate, an important commercial fertilizer. The coke

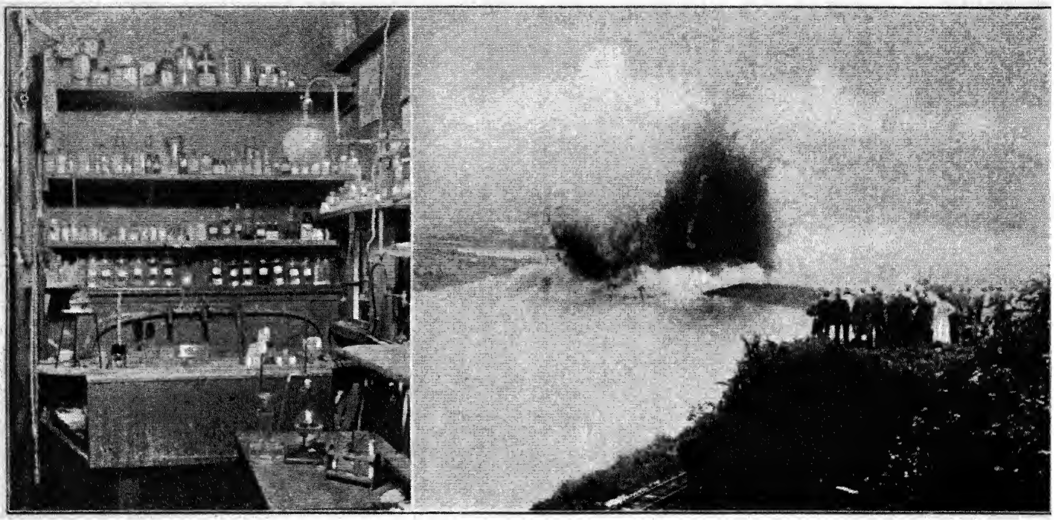
industry, which is simply another phase of gas manufacture, also yields ammonia.

Now just previously to the Great War a German chemist named Haber devised a process for making ammonia directly from the two elements which compose it, namely, nitrogen and hydrogen. Then to supplement this the famous German chemist Ostwald had perfected another process for oxidizing the ammonia into nitric acid. To develop these processes years of research were required and numerous difficulties had to be overcome. If the supply of ammonia from the coke and gas industries were sufficient the Haber process would be unnecessary, but there are so many other essential uses for this valuable product that it cannot be spared for the manufacture of nitric acid. Both of these processes are catalytic, that is, they are brought about and made possible through the influence of a third substance which greatly hastens the chemical changes taking place. Haber's method consists in passing nitrogen and hydrogen gases at 200 atmospheres pressure and 1300° Fahr. over finely divided uranium metal. For this purpose the gases must be exceedingly pure or the uranium catalyst will become "poisoned" and cease to act. The nitrogen is prepared from boiling liquid air. At ordinary pressure and a temperature of −190° C. the nitrogen boils off, leaving the oxygen. The hydrogen is made in a similar manner from "water gas" or is obtained from the electrolysis of a solution of caustic potash. Ostwald's process for the oxidation of ammonia to nitric acid consists in passing the gas mixed with air over heated platinum gauze. The oxygen in the air unites with the ammonia to form nitric acid and water. Great quantities of electric energy are not required in these processes and the raw materials used are inexhaustible. By their perfection Germany has made

herself absolutely independent of outside assistance for the manufacture of high explosives. As far as this factor is concerned she might continue the war indefinitely. But she did not dare to start this war until these processes had been invented and preparations for their application were complete. Considering the gigantic conflict which all these inventions have made possible, do you wonder that the fixation of atmospheric nitrogen has been pronounced the greatest achievement in applied chemistry of the last quarter of a century?

The United States Government in 1915 appropriated $20,000,000 for the construction of a nitrogen-from-the-air-plant and doubtless since the beginning of the war other steps in this direction have been taken. No excuse now remains for any nation to be deficient in the means of producing in abundance this fundamental requisite of self-defense and modern warfare.

From the battle of Cressy until the second half of the nineteenth century no great advance was made in the manufacture of explosives. Black gunpowder was still used. Then came *nitroglycerin*, the first of the modern high explosives. It is made by treating ordinary glycerin with a mixture of concentrated nitric and sulphuric acids. Three nitro-groups from the acid unite with the glycerin and a liquid product very closely resembling the original glycerin results. Its very great explosive violence is due to the fact that the molecule of nitroglycerin contains within itself the oxygen necessary for its own combustion. In old-fashioned gunpowder we have the carbon, sulphur and saltpeter in separate particles. The oxygen for burning the carbon must come from the saltpeter, outside itself, and therefore the combustion is comparatively slow. If gunpowder is to be used for blasting rocks a hole must be



A boy's laboratory and the chemical reaction from the explosion of a 40-ton blast of dynamite on the Panama Canal.

drilled and the powder tamped down to confine it. If unconfined, gunpowder will burn quietly without explosion or danger. But if nitroglycerin is simply placed on a rock its explosion will shatter the rock into a thousand fragments. The greatest force from nitroglycerin is exerted in the direction of the points of contact with it. Unmixed with other explosives it is useless for firing projectiles, for its explosion will shatter the gun itself. Nitroglycerin is not particularly easy to explode. It requires a certain sympathetic vibration imparted by a fulminate of mercury cartridge. Of course it may get this shock in other ways, and it is treacherous stuff to handle. When frozen it expands like ice and is more sensitive to percussion than when in the liquid state. It is very easy to make nitroglycerin in the laboratory, but unless you are contemplating suicide it is a dangerous pastime.

Alfred Nobel, a famous Swedish chemist, was the first to manufacture nitroglycerin in quantity. But he could not get transportation companies to handle it for him and was about to give up the business, when one day he observed that some of the stuff which had leaked from a broken can had been entirely absorbed by the sand in which it was packed. This gave him the idea of making *dynamite*, which is both safer to handle and less violent in its action.

The glycerin for this purpose was formerly obtained as a by-product of soap manufacture, but now so important has the explosive become that glycerin is the main product and soap the by-product.

Nitroglycerin and dynamite have been of immense importance in mining operations, the tunneling of mountains, the shooting of oil wells and such engineering works as the Panama Canal. Without them much of this work would have been impossible.

Another violent explosive somewhat similar in composition and preparation to nitroglycerin is *gun cotton*, or *nitrocellulose*. This is made by immersing purified cotton fiber in a mixture of concentrated nitric and sulphuric acids. In a few minutes it is removed, the excess of acid is pressed out and it stands for 24 hours for the process of nitration to take place. After washing and drying it is dissolved in a mixture of alcohol and ether, which converts it into a plastic mass suitable for molding and cutting into rods and grains of the proper size. This constitutes smokeless gunpowder. It does not readily explode and if ignited in the open will simply flash and disappear. In 1878 Alfred Nobel discovered that instead of using alcohol and ether for the absorption of gun cotton, nitroglycerin could be substituted. The result was a mixture of the two most violent explosives known to science. Nobel called it "*cordite*" and it proved to be an ideal ammunition for guns.

Picric Acid, about which we have heard so much during the war, is a yellow crystalline solid made from carbolic acid by treating with nitric and sulphuric acids. It, too, is a violent explosive used in making shells which liberate large quantities of poisonous gases when they burst.

The explosive, however, that has made the strongest appeal to the popular imagination is T. N. T. or *trinitrotoluol*. The starting point for this is toluol, one of the chief products of coal tar. This, too, is a mass of yellow crystals and a very "safe" explosive. It can be ignited, pounded with a hammer, riddled with bullets and subjected to all sorts of rough usage without danger of explosion. But when it gets that particular sympathetic vibration from a fulminate of mercury cap, there begins the wild dance of the atoms and before they recover their

equilibrium the projectile against which they pushed has sped ten miles on its mission of destruction and death. Shells loaded with 500 pounds of T. N. T. are in common use, and the awful havoc wrought on both sides of the Western Front and elsewhere in the war zones of Europe is the best evidence of the vast quantities of energy stored within.

Thus the consideration of high explosives shows how the World War had to wait for the chemists to get ready. But we must not forget that explosives and their destruction are mere incidents in the achievements of modern chemistry. Chemists in general cannot be held accountable if mad despots turn their discoveries into instruments of annihilation. The main purpose of chemistry is to discover nature's secrets and thereby bring the peaceful industries of the earth to a higher degree of perfection. But so complex and interwoven are the industries and instruments essential both to peace and war that any real progress may be turned in either direction.

The Coal Tar Industry.—It is not so many years ago that coal tar had no more important use than to keep the crows from pulling the corn in the farmer's fields. Dirty, black, foul smelling stuff, it was regarded as an unmitigated nuisance and for a hundred years was treated as pure waste. To-day it is probably the most valuable single by-product of chemical manufacture. It is a tremendous resource both of peace and war. From it we draw the explosive that wounds the soldier and the healing drug that effects a cure. Like a magician the chemist makes this unsightly mass yield all the brilliant hues of modern dyestuffs. He pulls out of it the most delicate perfumes known to nature. Here the physician finds an inexhaustible storehouse of powerful drugs for the stilling of pain,

the allaying of fever and antiseptic uses. The connoisseur of sweets finds a compound five hundred times sweeter than any sugar. Chemicals for the prevention of vegetable decay and pitch for paving and roofing are useful by-products.

Coal tar is a by-product of the coke and gas industries. To make either coke or gas, soft coal is heated in closed retorts out of contact with the air. This process is called "destructive distillation." The gaseous matter driven from the coal is first made to pass through a 3-foot pipe called the *hydraulic main* in which the coal tar is extracted, and it is then passed on to the *scrubber* where the ammonia is removed. For many years and until very recently in this country so-called beehive coke ovens were employed for this purpose and all the gas, coal tar and ammonia allowed to burn as they escaped. In this way $75,000,000 worth of by-products went up in smoke each year. But the coke obtained from these ovens was used in the smelting of iron ore and nothing else was desired. It was an expensive process to install the modern by-product coke oven and "cheaper" to allow Germany to supply us with the necessary dyestuffs and other coal tar products. Our capital could find more profitable employment in other ways. Besides, we imported only about $10,000,000 worth of these products each year, and such a small item was not considered worth bothering with. The fact that the textile industry, the manufacturers of inks, paints and stains and all other industries using colors in any way were dependent upon Germany for their dyestuffs was not taken into account. As a result, when the war broke out there was an immediate dyestuff famine in every country of the world outside of Germany. Colors could not be had to dye the uniforms of the soldiers. Even our own Government had

to beg Germany for enough dyes to color our stamps and paper money and to get permission to bring them over in Dutch ships. But happily this has passed and the United States now possesses a dyestuff industry which only the indifference of Congress will ever allow to be displaced by German competition.

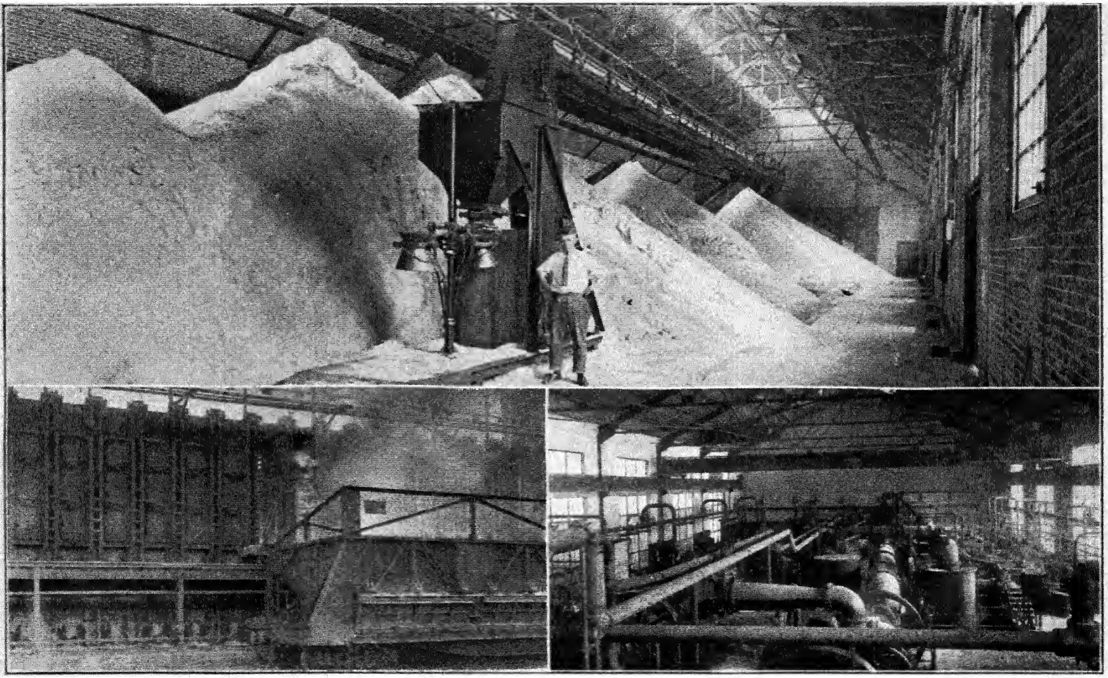
The dyestuff industry and the beginning of the coal tar romance had its origin in the research work of a mere boy. In 1856 Sir William Perkin, then a lad of seventeen, was at work in his private laboratory endeavoring to extract the drug quinine from coal tar. One day as he added alcohol to a dirty, black mass that had precipitated in his beaker, there appeared a brilliant purple color. This was mauve, the first of a host of aniline dyes. He extracted the stuff and so contagious was his enthusiasm that he persuaded his father and brother to set up a factory for its manufacture. With no previous experience in chemical industries, he overcame all obstacles and placed his product on the market. A few years later from another coal tar derivative, he extracted alizarin, the brilliant "turkey red," which for many years had been obtained from the madder plant. That event sounded the death knell of the madder plant industry. News of these discoveries spread throughout Europe and the chemists in other countries went to work, particularly in Germany. The production of gorgeous colors of every hue followed each other in rapid succession. Dye works sprang up everywhere. But the British government, giving no encouragement to the industry, it passed largely under German control.

For centuries indigo had been obtained from the indigo plant. The Egyptian mummies are found wrapped in clothes dipped in this ancient dyestuff. But in 1879 a famous German chemist, Adolph von Baeyer, produced

indigo artificially from coal tar products. The dye plant of the Badische Anilin und Soda Fabrik then took up the problem and after fifteen years of exhaustive research and the expenditure of millions of dollars, synthetic indigo at a few cents a pound became a fact. The value of the annual product of the indigo planters quickly dropped from $20,000,000 to $300,000. A brilliant array of red, yellow and green derivatives of indigo have also recently been obtained.

Now nearly 2,000 coal tar dyestuffs are known. They cover every shade and hue and meet every requirement of taste and fashion. Millions of capital and thousands of men are engaged in the industry. Not only do these plants produce dyestuffs but all the other species of the numerous tribes of coal tar products. During the war the German plants have directed their energies largely toward the production of medicines and explosives. They constitute one of the great war-making assets of the nation. But under the spur of four years of necessity, the other nations of the earth have become independent of Germany, and never again will she regain the immense monopoly of the coal tar trade that she enjoyed before the war.

The By-Product Coke Ovens.—At the beginning of the war there were in this country comparatively few by-product recovery plants. By the summer of 1915, so great was the demand for these products in the munition factories that the price of benzol had gone to 80 cents a gallon and that of toluol to $7 a gallon. Under such stimulus the number of these plants increased until on January 1st, 1918, there were in operation in this country and Canada nearly 10,000 recovery ovens. In the old wasteful beehive oven not only were the coal tar, gas and ammonia lost, but for every ton of coke produced 200 pounds of coal



By courtesy of the H. Koppers Company
Manufacturing the fertilizer ammonium sulphate, modern coke ovens and a by-product recovery plant.

were needlessly burned in the process. Converting the combustible portion of these products (all save ammonia) into their equivalent value in pounds of coal and adding the 200 pounds needlessly burned, it is found that out of every ton of coal coked 825 pounds were lost. Rather a wasteful process considering the great fuel shortages that have been experienced. It might be said, however, that there is an abundance of coal in America for centuries to come and shortages have been due solely to unprecedented demands and lack of labor and transportation facilities.

The ovens now in operation carbonize approximately 47,400,000 tons of coal per year yielding 35,000,000 tons of coke, the balance being converted into coal tar, ammonia, gas and benzol oils. These figures do not include the numerous city gas plants which also produce similar products. Here is an economy forced upon the nation by the war that would have required a quarter of a century and more of peace time progress to effect.

In the old by-product ovens the bulk of the benzol, toluol and xylol together with considerable quantities of napthalene were left in the gas. These substances enriched the gas and for purposes of illumination were desirable, but with the modern gas mantle wholly needless and pure waste. Therefore, the modern ovens have added benzol recovery towers in which the gas is scrubbed with solvent oils. Formerly the supply of benzol, toluol, etc., all came from the fractional distillation of the coal tar, but now 95% of it is recovered from the gas. If all the coke required by this country were coked in by-product ovens having benzol recovery equipment, it is estimated that 110,000,000 gallons of benzol would be obtained each year. When it is understood, too, that benzol can be used in automobile engines with an increase of 20 per cent per

gallon in mileage, we shall better appreciate what this recovery means to the nation. Before the war Germany used 50 per cent of her benzol in internal combustion engines.

In addition, benzol is the starting point in the manufacture of aniline oil and the host of dyestuffs from it. Carbolic acid, formerly distilled entirely from coal tar, is now made largely from benzol. Benzol is used in the manufacture of paints, stains and varnishes; for cleaning purposes; as a solvent for grease, fats and rubber and in the manufacture of artificial leather. Toluol with nitric and sulphuric acids gives the powerful explosive trinitrotoluol and is used in the production of such substances as saccharin and benzoic acid. Saccharin is the compound 500 times sweeter than sugar.

The most of the ammonia recovered in these plants is passed into sulphuric acid and is converted into the important fertilizer, ammonium sulphate. Some of it is dissolved in water for laboratory and household purposes and some is used for the manufacture of artificial ice. If necessity required ammonia might be oxidized to nitric acid by Ostwald's process.

The bulk of the coke is used to reduce iron ore in the blast furnaces of the country. It is nearly pure carbon and its combustion produces intense heat.

Only a small portion of recent chemical progress has been given in the foregoing paragraphs. But it would be difficult to find any industry of importance that does not have its chemical problems and nowadays its laboratory and staff of trained chemists. As the late Robert Kennedy Duncan said, the world is learning the difference "between the sway of the finger of Science and the ancient Rule of Thumb."

SOME CHEMISTRY EXPERIMENTS

1. *Gunpowder.*—To prepare old-fashioned gunpowder, mix thoroughly 30 grams of finely powdered potassium nitrate with 5 grams each of powdered charcoal and flowers of sulphur.

Place the mixture on a square of asbestos and ignite with a long wax taper.

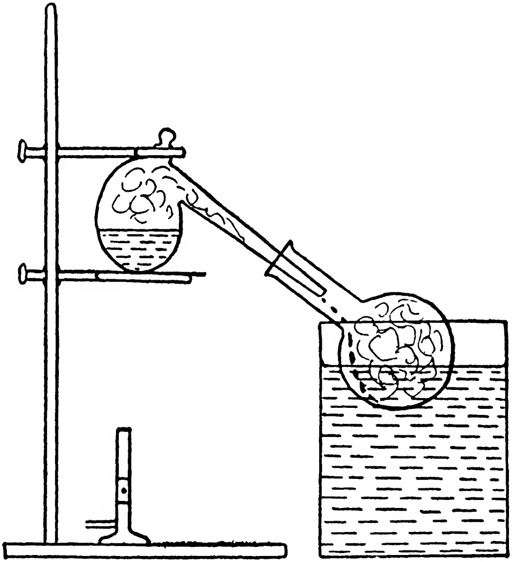


FIG. 99.—Preparation of nitric acid.

If thoroughly dry, finely powdered sodium nitrate, Chili saltpeter, may be substituted for the potassium nitrate.

2. *Preparation of Nitric Acid.*—Arrange a ring stand, tubulated retort and condensing flask as shown in Fig. 99. Place in the retort about 15 grams of sodium nitrate and

by means of a funnel pour into it 10 cubic centimeters of concentrated sulphuric acid. Insert the stopper in the retort and heat the mixture very gently, using a small flame.

Very soon small drops of the acid will be seen condensing in the neck of the retort and trickling down into the flask. In the heating of the retort so far as possible avoid decomposing the acid. If brown fumes appear remove the flame for a few moments. Continue the process as long as any nitric acid distils over.

The liquid collected in the flask is very strong nitric acid and great care must be observed in handling it.

To show its *oxidizing action* pour a very little in the bottom of a test tube and just above it place a loose plug of boiler felt or excelsior. Then holding the test tube with a holder heat the acid until it boils. As its hot vapor comes in contact with the boiler felt or excelsior the latter will take fire and burn vigorously.

It is this oxidizing action of nitric acid that makes it valuable in the manufacture of explosives.

The *solvent action* of nitric acid on metals can be shown by pouring a little on a small piece of copper in the bottom of a test tube and then adding a few drops of water. The brown fumes that come off are nitrogen peroxide.

Nitric acid is the best general solvent for metals.

Another experiment to show the *oxidizing action* of nitric acid can be carried out as follows:

In the bottom of a test tube place a little sodium nitrate and cover with concentrated sulphuric acid. Heat in the Bunsen flame, holding the test tube with a holder, and when the vapor of nitric acid is coming off rapidly, thrust into it a glowing splint. The splint will immediately burst into flame. It is best to hold the splint with pincers or tongs.

3. *A Flash Powder.*—Mix equal parts of powdered potassium chlorate and magnesium powder. Place the mixture on an asbestos square and ignite with a *long* wax taper. Do not try to light it with a match. An instantaneous flash of dazzling brilliancy results.

Here, too, we have oxidation. The potassium chlorate contains three atoms of oxygen in each molecule which it very readily gives up to the magnesium. This mixture is used in many flash light powders for photography work.

4. *Red Fire.*—Finely powder 1 gram of potassium chlorate and 11 grams of strontium nitrate *separately.* (*They must not be powdered together.*) Then make a mixture of the chlorate and nitrate together with four grams of flowers of sulphur and ½ gram of lampblack. Place the mixture on an asbestos cardboard and ignite with a long taper. An intensely red flame results.

For ignition purposes touch paper is useful. It is made by soaking unsized paper in a saturated solution of potassium nitrate and drying. It will burn like the fuse of a firecracker and cannot be extinguished by blowing.

5. *Green Fire.*—Mix as before 3 grams of finely powdered potassium chlorate, 8 grams of finely powdered barium nitrate and 3 grams of flowers of sulphur. Place the mixture on asbestos cardboard or paper and ignite with taper or a short fuse of touch paper. To use touch paper make a conical heap of the mixture and insert a strip of the paper in the top.

6. *Purple Fire.*—Finely powder and mix 2 grams of copper sulphate, 2½ grams of flowers of sulphur and 15 grams of potassium chlorate. Ignite on asbestos with touch paper or taper.

For pulverizing substances a small earthenware mortar and pestle are essential.

7. *Nitric Oxide and Nitrogen Peroxide.*—These compounds are intermediate products in the manufacture of nitric acid from the air.

Arrange apparatus as shown in Fig. 100. The generator may consist of a wide-mouthed bottle into which is fitted a two-holed rubber stopper carrying a thistle tube and bent glass tube. The thistle tube must reach to the bottom of the bottle. Fill a basin about half full of water and invert in it a bottle filled with water. To the bent glass tube connect a 15-inch length of rubber tubing, to the opposite end of which is fitted a glass delivery tube.

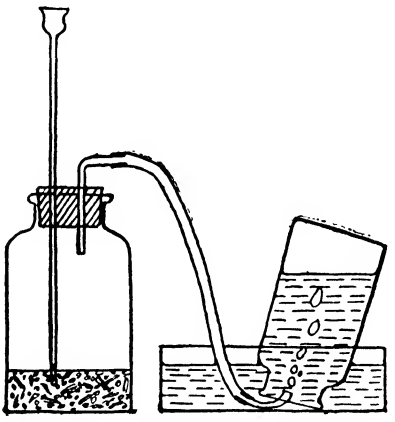


Fig. 100.—Preparation of nitric oxide.

In the generator put a few copper rivets and just cover with water. Add about a third as much concentrated nitric acid and wait for the action to start. Don't grow impatient, for the action will be vigorous enough when it does come. Sometimes it is necessary to add a little more acid. If the action becomes too vigorous, slow it down by adding water. (Pour both acid and water through the thistle tube.)

When the action starts, place the delivery tube beneath the inverted bottle and allow the gas to displace the water. Two bottles of the gas may be collected if desired. When the bottles are full stop the action by pouring water through the thistle tube.

It will be noted that the gas in the bottle is colorless. This is nitric oxide. It is also insoluble in water, for if it were soluble the water would rise in the bottle.

Now lift one of the bottles from the water and the gas immediately turns reddish brown. (Do not breathe the fumes.) The nitric oxide has taken on oxygen from the air and formed nitrogen peroxide.

Now place the bottle mouth downward in the water and the water will immediately rise in the bottle, the brown color disappearing at the same time. The nitrogen peroxide has dissolved in the water.

Slip a glass plate under the mouth of the bottle and remove it, reinverting at the same time. Now add to the water in the bottle a solution of blue litmus and it will immediately turn red, showing the presence of an acid. In dissolving in the water, the nitrogen peroxide forms a mixture of nitric and nitrous acids. This is what happens in the making of nitric acid from the air.

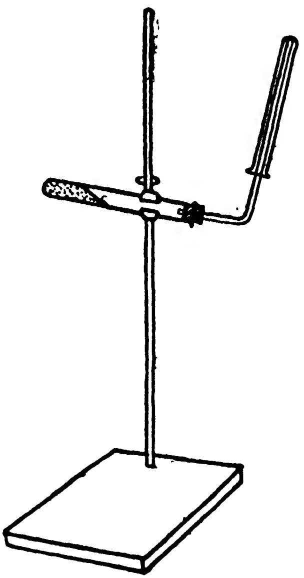


FIG. 101.—Preparation of ammonia.

8. *Preparation of Ammonia.*—On a paper mix equal quantities of sal ammoniac and slaked lime. Fill a test tube one-half full of the mixture and fit it with a one-holed stopper and bent delivery tube as shown in Fig. 101. Heat the test tube gently with a small flame and hold over the delivery tube a strip of moist red litmus

paper. It turns blue as the ammonia gas is given off. This is a test for ammonia.

Now invert over the delivery tube a dry test tube and continue to warm the mixture. After a few moments remove the tube full of ammonia gas and thrust it mouth down in a dish of water. The water will rise and fill the tube, showing the great solubility of ammonia. The gas is collected upward because it is lighter than air.

The experiment showing the solution of the ammonia in the water may be varied by adding to the water in the dish a little blue litmus and coloring it red by the addition of one drop of acid. Now when the *dry* test tube of ammonia gas is inverted in the red litmus the water will rise as before but will be immediately turned blue.

9. *Preparation of Hydrogen.*—Hydrogen used for the inflation of balloons and Zeppelins and in the Haber process of making ammonia may be made in the same apparatus as that used for nitric oxide.

Instead of copper and nitric acid use zinc and dilute sulphuric acid. The acid may be prepared by pouring 15 cubic centimeters of concentrated sulphuric acid into 90 cubic centimeters of water. (*Never pour water into the acid.*)

Cover the bottom of the bottle with granulated zinc and arrange the apparatus exactly the same as in the nitric oxide experiment, but do not place the delivery tube under the inverted bottle at first. Make all the joints perfectly tight and add the acid until the zinc is well covered. If the action does not start readily add a few drops of a solution of copper sulphate. Be sure that no flame is near the generator.

When the action has been going briskly for about two minutes, place the delivery tube underneath an inverted

bottle of water and displace the water. Fill three bottles with the gas in this way. Stop the action by pouring water through the thistle tube.

Remove one of the bottles and hold it mouth downward over the flame of a Bunsen burner. Note that the hydrogen burns with an almost colorless flame.

In the right hand hold a bottle of hydrogen mouth downward and beside it in the left hand an "empty" bottle also mouth downward. Now pour the hydrogen *upward* into the "empty" bottle by quickly bringing beneath it the mouth of the bottle of hydrogen. After a moment bring both bottles mouth downward to the Bunsen flame. What property of hydrogen is shown by this experiment?

Allow the third bottle of hydrogen to remain mouth upward for two minutes and then present to the flame. Where has the hydrogen gone? Why?

10. *Destructive Distillation of Coal.*—In a hard glass test tube provided with a one-holed stopper and short straight glass tube place some powdered soft coal. Heat this strongly in the Bunsen flame and after a few moments ignite the gas. When no more gaseous matter can be driven off allow the test tube to cool. On the sides will be found some black, sticky stuff. This is the coal tar or that part that was not driven out and burned with the gas. Knock out the residue in the bottom and you will find a dry porous piece of coke. If you had placed a strip of moist red litmus paper in the gas before igniting it, you would probably have obtained the test for ammonia.

Chapter XVIII

THE STORY OF IRON AND STEEL

Hand in hand with the rise and fall of nations has gone proficiency in the working of metallic ores and particularly in the metallurgy of iron and steel. At what time in the remote past primitive man through his knowledge of fire passed to a knowledge of metals and their wonderful properties, so indispensable to his mastery of the earth, it is idle to conjecture. Certain it is that for long centuries before the Christian Era, metal working was a highly perfected art. Whether or not copper and tin were the first metals to be used and in their alloyed form of bronze characterized a long period of history in which the use of other metals was unknown, it is difficult to determine. Ancient ruins and the easy metallurgy of these ores would suggest this to be true. And yet iron has been found in the pyramids of Egypt built 4,000 years before Christ. Much evidence, too, points to a knowledge of iron by the Assyrians, Chaldeans and Babylonians, who occupied the plains of Mesopotamia at a much earlier period. But whatever the truth, the mastery of metals and their skillful adaptation to the varied arts of peace and war have spelled power and dominion—dominion at first over the material elements of nature, followed by the military and political sway of empire.

Iron and steel have been the world's symbols of power from the days of Rome to the present moment. Ancient Spain before the rise of Rome was skilled in the working of

iron. Hannibal's men equipped with Spanish swords made sad havoc in the Roman ranks at the battle of Cannæ, in 216 B. C. The famous blades of Damascus and Toledo even point to the tempering of steel as something of a lost art. When Cæsar invaded England he found the Britons in the possession of iron. The Scandinavian Vikers used iron in their vessels even in Roman times. The victory of William the Conqueror in 1066 must be attributed to warriors clothed in steel armor, having steel weapons in their hands and mounted on horses shod with iron. The rise of Great Britain to world-wide power has been coincident with the growth of her steel mills and the supremacy which she enjoyed in that industry until toward the close of the last century. With the increase in the output of her mines and the marvelous expansion of the Krupp steel works, Germany, before the war, was rapidly climbing to her "place in the sun." Indeed, it is her control of iron and steel, including the stolen mines of Belgium and northern France, that has made her the military octopus of the world. But across the ocean in America the steel industry has surpassed that of every other nation. Nowhere else in all the earth are there such inexhaustible stores of ore, coal and limestone. The stupendous output of her thousands of furnaces is being forged into steel without limit for armor plate, big guns, steel ships, aëroplanes, locomotives, shells, motor trucks and a score more of war-making essentials that in an avalanche of steel, steel and more steel will overwhelm the powers of darkness and international brigandage. Steel is the fundamental essential of every war-making activity and that nation that controls it in largest measure can build the biggest merchant fleets, the most powerful guns, the largest battleships, the most aëroplanes and that almost infinite supply of ammunition

indispensable to a military victory. Germany's output of steel, great as it is, is insufficient to forge the chains of world dominion. She has decreed for herself "world dominion or downfall" and the answer of the mightiest steel-producing nation of the world is downfall.

Primitive man ages ago probably stumbled on to the method of working ores. As he raked over the embers of some spent fire, he discovered globules of bright metal. It may have been tin or copper or perhaps iron. But whatever the metal, its lustre and properties of toughness, hardness and malleability must soon have demonstrated its superiority to wood and stone for hunting purposes and weapons of warfare. A repetition of this experience with the fire followed by examination of the rock upon which it was built gradually led to a knowledge of certain ores and a deliberate attempt to duplicate the process.

The Blast Furnace.—But a knowledge of the metallurgy of iron came very slowly. From Roman time to the discovery of America very little progress was made. The first "blast furnace" consisted of a hole in the ground into which alternately lumps of ore and charcoal were thrown, followed by blowing with a hand bellows. By vigorous work two men squatting over this crude furnace would produce a dozen pounds of the metal in a day. For comparison we may note that one of the big blast furnaces at any of our modern steel plants turns out 400 tons of pig iron every 24 hours. The famous Catalan forge representing the acme of the metallurgist's art all through the Middle Ages and until very recently still used in remote corners of the earth originated in Catalonia, Spain, nobody knows when. It closely resembles a blacksmith's forge, consisting simply of an open-top, brick-lined furnace fitted with a hand bellows. The heat obtained was not sufficient to melt

the iron but left it in a pasty condition suitable for hand forging. When the iron master learned the desirability of using a flux to unite with the earthy impurities in the ore and by what tedious and baffling experiments he at last discovered in limestone the ideal material for this purpose, no record discloses.

Iron making as an industry, however, cannot be said to have established itself until the invention of the present type of blast furnace following the revival from the general lapse of knowledge experienced during the mediaeval period. The first furnace built on modern lines appeared in the lower Rhine Valley. It was only about sixteen feet in height and still unable to melt the iron. Improvements were made and the height increased until by 1340 the Belgian "blow oven" yielded molten metal and the first cast iron in history was produced. The molten iron was drawn off in one large pool from which numerous smaller depressions led for the purpose of cooling. Because these depressions resembled a brood of young pigs the product of the blast furnace very early came to be called "pig iron."

The fuel used in these early furnaces and for several centuries after was charcoal. Timber was abundant and charcoal was ideal both for fuel and the reduction of the ore. The destruction of the forests, however, particularly in England, produced a decline in the industry for a number of years. Then about the middle of the eighteenth century Abram Darby of England discovered the process of coking bituminous coal. Coal was abundant in England and had been in common use for more than two hundred years. Furthermore, the coal and iron deposits were side by side, thus making ideal conditions for the steel industry. There it was, too, in the small island king-

dom that this great basic industry had its first phenomenal development.

In America forges and furnaces sprang up in every colony. The first iron smelted was in Massachusetts in 1644. Centers of iron manufacture multiplied for two hundred years. The industry in those days was purely local, but the numerous forges scattered along the Atlantic seaboard and extending inland to the Alleghenies and the Ohio Valley did valiant service in the early pioneer days. They provided muskets, cannon and shot for our first two wars and the implements necessary to the subduing of a new country. The coming of the locomotive and the railroads in 1831 gave a tremendous impetus to the industry and started it toward that wonderful expansion that more than anything else has won for America the commercial supremacy of the world.

The product of the old Catalan forge was wrought iron, or malleable iron. Prolonged heating with charcoal and later with the addition of a flux together with hammering and reheating produced a fairly pure quality of iron. It is commonly called soft iron and is the sort of iron a blacksmith uses for forging and welding. At no point of the process had it been melted. The product of the blast furnace, however, is drawn off in a molten condition and is not nearly so pure. By melting and coming into intimate contact with the contents of the furnace the iron dissolves carbon, phosphorus, sulphur and silicon. The blast furnace process is much quicker, easier and cheaper, but the impurities make the iron useless for many purposes. It is brittle and cannot be forged either hot or cold. The impurities, however, give it a lower melting point and where used without change it is remelted and cast.

The Puddling Furnace.—Therefore, it became necessary

to purify blast furnace iron by reheating and hammering it in a forge. This was a very laborious process and did much to rob the blast furnace of any advantage it possessed over the older method. But in 1784 Henry Cort, an Englishman, invented the "puddling" furnace for changing the pig iron into wrought iron. It consisted of a basin-like hearth with a sloping, arched roof and a fire grate just beyond a low partition at one end. The pig iron is melted in this hearth and the flames and hot gases from the fire being deflected downward upon its surface burn out the carbon and other impurities. The hearth is usually first covered with a layer of iron oxide to assist in the oxidation. As the process continues and the iron becomes more nearly pure its melting point rises, making it assume a pasty condition. At this point a workman reaches into the furnace with a long rake and rakes or "rabbles" the pasty lumps over to quicken the process of oxidation. In this way a very pure product is obtained, but its pores are full of slag and to remove this Cort provided grooved rolls which repeatedly squeezed the hot iron and very quickly freed it from the slag. The puddling furnace was a vast improvement and for producing wrought iron is still used.

Another Englishman, J. B. Neilson, in 1828 discovered that by preheating to about 600° Fahr. the blast of air for the blast furnace, its output could be doubled with no increase of fuel. Here was a very great cheapening in the cost of pig iron and coupled with the improved methods of converting it into wrought iron resulted in a much wider field of usefulness.

Early Steel Making.—Steel was not much used in those days but for some purposes such as cutlery, the finest edged tools and rails for the locomotives, wrought iron

was too soft. Now the fundamental difference between wrought iron and steel is in the percentages of carbon that they contain. Wrought iron is nearly pure iron having not over .3 per cent of carbon, while steel has a carbon content of from .5 to 1.5 per cent. Wrought iron is tough, pliable, inelastic and adapted to forging. To change it into hard elastic steel that can be tempered and made to take an edge it must be made to take on carbon. This was accomplished by placing bars of the iron together with charcoal in a closed retort and heating them red hot. The heating was continued for several days and the iron gradually absorbed the carbon, being converted into a uniform, high-grade steel, called blister steel. The process was slow and although the steel was of excellent quality, its cost for extensive use was prohibitive. As the needs for hard, tough, elastic iron multiplied, it became increasingly apparent that a quicker and cheaper process of producing steel must be developed.

The Bessemer Process.—The solution of the problem was soon forthcoming. In 1856 Sir Henry Bessemer presented to the British Association for the Advancement of Science his now famous process for quickly and cheaply converting pig iron into steel. It marked an epoch in world progress and ushered in the Age of Steel. Without it the marvelous material and commercial expansion of the last half century would have been impossible. Fleets, railroads, locomotives, skyscrapers, automobiles, big guns, machinery of all types and a thousand more necessities of modern industry never would have risen above the threshold of accomplishment.

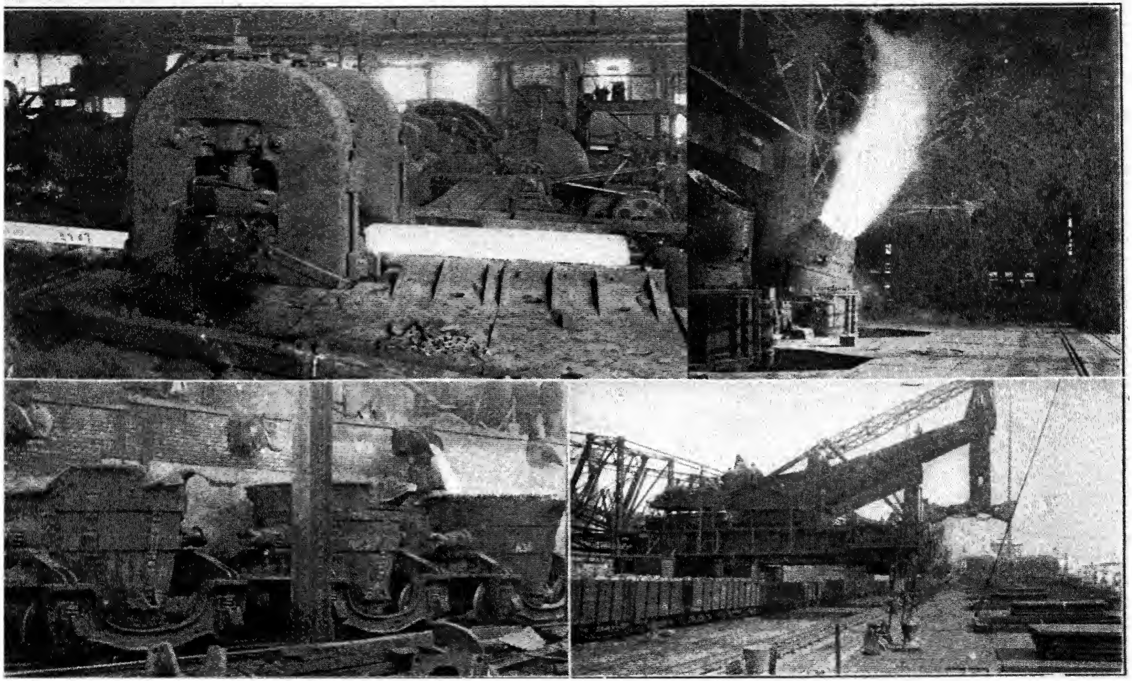
Sir Henry Bessemer was gifted with a genius for invention. When only a lad of eighteen he devised an improved method for stamping deeds which was adopted by the

English Stamp Office without remuneration to the youthful inventor. Then in rapid succession he invented machinery for making figured velvet, a type-casting machine and a process for the manufacture of bronze powder. In 1854 he was working in France on an invention relating to projectiles. The necessities for this work brought forcibly to his attention the inadequacy of existing methods for the manufacture of steel. The result was a series of experiments in an old factory at St. Pancras and the development of the Bessemer process. He conceived the idea of burning out the impurities from molten pig iron with a powerful blast of air. For this purpose he provided a huge egg-shaped crucible capable of holding 15 or 20 tons of the molten metal. It was lined with silica and mounted on trunions, one of which was hollow and led to a perforated bottom for the passage of the blast of air. The crucible was rotated on its trunions to receive the charge and then tipped back in a vertical position for the air blast. As the oxygen of the air passed upward through the white-hot liquid iron, the impurities were quickly burned out, not over twenty minutes being required for almost as many tons of metal. The "blow" is accompanied by a deafening roar and a sheet of flame, changing rapidly from red to white and then to a faint blue. When the color of the flame indicates that the carbon is gone, the blast is shut off and the requisite quantity of an iron alloy rich in carbon and manganese is added. After the blow the contents of the crucible are in composition essentially wrought iron, but to make steel carbon must be added. The purpose of the manganese is to deoxidize the iron which is left by the blow in a highly oxidized state. This process of incorporating the carbon and deoxidizing the iron requires but a few moments and the now molten

steel is quickly poured or "teemed" into ingot molds waiting below on a train of flat cars to receive it.

Bessemer's announcement was received by the iron makers of England with no little skepticism and ridicule. Its application in many places proved to be a disastrous failure. At that time Bessemer, himself, had not perfected the process in all its details as described above and as we know it to-day. With undaunted perseverance, however, he went to work and by 1859 all difficulties had been overcome. The vitally important matter of adding the carbon-manganese alloy was due to Robert Mushet. But previous experiences had brought such ill-repute to the process that no one would have anything more to do with it. Therefore, Bessemer, with the financial assistance of friends built his own works at Sheffield and entered into open competition with his critics. The results very shortly demonstrated the superiority of his process, and the production of high-grade Bessemer steel at about $100 a ton cheaper than the prevailing market price forced a speedy surrender of the "enemy." Bessemer licensed the use of his patents both at home and abroad and ten years after the first announcement, his revenue therefrom was a half million annually. Both from this source and his great works at Sheffield, he amassed a large fortune. In fourteen years his steel plant had yielded 81 times its original cost. In later years he devoted himself to an unsuccessful invention for preventing the rolling of a ship at sea and to the improvement of telescopes. His country knighted him, he was honored with a fellowship in the Royal Society and the world will never cease to be grateful to the inventor who made possible cheap and abundant steel.

The inability to handle ore containing more than very



By courtesy of the Lackawanna Steel Company.

Rolling a steel ingot, a Bessemer converter in action, teeming molten iron and unloading ore at the docks.

small amounts of phosphorus and sulphur in the Bessemer converter was one of the early difficulties experienced with the process. Phosphorus made the steel brittle when cold and sulphur made it brittle when hot. Consequently only certain ores could be worked by the Bessemer method and many very rich deposits were unavailable because of their phosphorus content. Then in 1878 Messrs. Thomas and Gilchrist devised the "basic Bessemer process." Instead of lining the converter with sand, an acid substance, as had been done before, they substituted a dolomite lining which is basic in character, or the opposite of acid. Phosphorus, which is, itself, acid in character unites with the basic lining and is thus eliminated. In addition, to assist in the removal of the phosphorus, lime, another basic substance, is put in with the charge of molten pig iron.

Open Hearth Process.—The Bessemer process had the two great advantages of being quick and cheap, but it lacked control. So quickly is the pig iron converted into steel that there is no opportunity to test the product and govern in any scientific way its quality. The whole success of the process depends on keeping the iron in a molten condition and with no other source of heat than that from the burning impurities, the iron would soon "freeze" if all haste were not made.

But in 1856, the same year that Bessemer took out his patents, William Siemens invented another process for steel making very similar to the puddling furnace for wrought iron. About eight years later a Frenchman named Martin improved it by adding a regenerating system for conserving the waste heat and made the process a commercial success.

In the open hearth furnace on each side of an immense hearth are two large chambers loosely fitted with a fire-

brick checkerwork. The hearth is covered with an acid or basic lining according to the kind of ore to be worked and this is followed with a charge of pig iron, scrap steel and iron oxide. Connected with the brick checkerworks

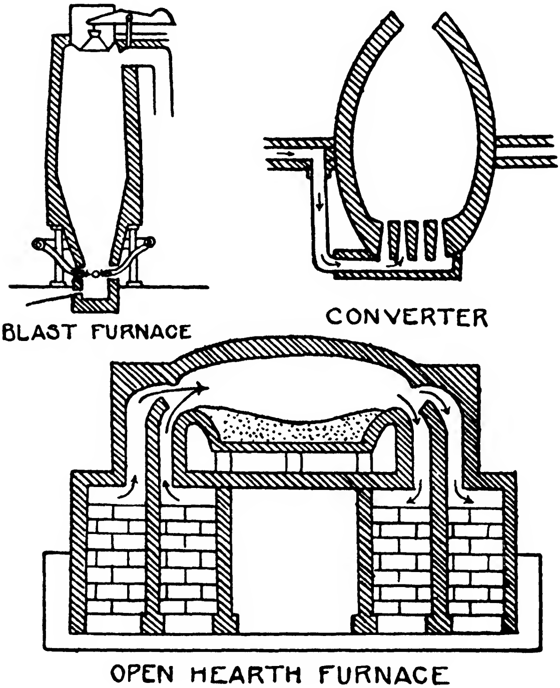


FIG. 102.

are supplies of air and gas. The gas is generated in a gas producer by blowing air in the proper proportion through a hot bed of coal. Through one checkerwork on one side gas is blown and through the other air, the gas and air meeting over the hearth and burning with a fierce heat.

At the same time the hot combustion gases sweep out through the checkerworks on the other side, raising them to a white heat. After about 20 minutes the gases are shifted, the air and producer gas entering through the hot checkerworks and the combustion gases passing out through the opposite ones. In this way energy is saved and the pre-heating of the gas and air increases enormously the temperature of the furnace. As a result the pig iron and scrap steel melt and the flames and iron oxide burn the impurities out of the iron. The time required for a charge is about 8 or 10 hours, but the process is under perfect control. Samples are removed and tested. If too acid, lime is added; if too basic, silica; if the carbon content is too high more scrap steel is added and at the end just the requisite quantity of ferro manganese to give the grade of steel desired.

Open hearth steel costs more to make but it is more uniform, more dependable and of greater strength than that made by the Bessemer process. So great is the demand for open hearth steel in this country that the Bessemer converters are being rapidly displaced. They afforded an excellent bridge over which to pass from the age of iron to the age of steel, but having done their full part of the world's work, like the stage coach and sailing vessel, they must give place to something better.

The Supremacy of the United States.—In 1880 the steel industry in England had reached its zenith, but from that date the ascendency of America has been rapid and certain. To-day the United States produces more than half of the total steel output of the world. Favored with the richest and most abundant deposits of ore, coal and flux to be found anywhere in the earth and having a tariff-protected home market coupled with a land of boundless and unde-

veloped resources, the growth of the industry in this country has become one of the marvels of the nineteenth and twentieth century progress. The scarcity of labor incident to the rapid growth of a new country has forced the industry upon a machine basis. Electric and steam shovels, cranes, rollers, shears, stamping machines and furnace charging apparatus besides a host of other labor-saving devices have eliminated the human factor to a very large extent. In this respect the industry here differs from that of any other country.

The better ores having been exhausted in the East, about 1880 the ore supply began to shift to the Lake Superior region where lie the richest and largest deposits of the earth. But the deposits of coal and the furnaces were in the East and therefore the ore must be transported a thousand miles to the iron centers about Pittsburg and the lake ports. The problem was stupendous, but the Great Lakes afforded a natural highway and it was soon solved. The whole of this thousand-mile route fairly bristles with machinery at every point from mine to furnace. The ore lies on the surface or very close to it and is loaded directly into the long ore trains with a myriad of steam shovels. The ore trains run to Duluth, about 80 miles distant, and automatically dump their loads directly into huge pockets on the docks. Large ore freighters, little more than hollow shells but with an enormous capacity, lie alongside the docks and through spouts and hatches placed at intervals of 12 feet are filled at the rate of from 80 to 300 tons per minute. A ship holding close to 10,000 tons has been loaded in 25 minutes. One of these ungainly "whale backs" has scarcely had time to tie up before it is ready to start on its return trip toward the seething furnaces of the East.

The unloading machinery at the lake ports works on an

equally large scale. In the old days these immense cargoes were unloaded with shovels, buckets, windlasses and wheelbarrows. But all this has changed. Huge clam-shell unloaders dip into the hold of the ship and when their gigantic jaws come together they scoop up 17 tons of ore at a time and quickly lift it into the bin above. From the bin it is run into waiting ore cars below to be carried to the furnaces or it is deposited in the buckets of a great cantilever bridge to be transferred to the reserve stock pile. In 3 hours this electrically operated machinery will unload 10,000 tons of ore and before the war it was done at a cost of 2 cents per ton.

At the steel plant this ore, which at no point of its thousand mile journey has been lifted by human muscle, is hoisted 90 feet to the top of a huge blast furnace that swallows every day 800 tons of ore, 400 tons of coke and 100 tons of limestone, yielding an output of 400 tons of pig iron. From the blast furnace the iron, still in the molten condition, is run into huge ladles and carried directly to the converters or open hearth furnaces where very shortly it becomes steel and in the shape of 7,000-pound ingots is deposited in soaking pits preparatory to its trip through the rolls to be shaped into steel rails, rods, girders or what not. Machine handled at every point, it may be truly said that "steel is not made with hands."

Some faint idea of the magnitude of the steel industry in the United States may be obtained from the fact that in 1917 approximately 80,000,000 tons of ore were mined, yielding half that number of tons of pig iron and representing in the unconverted state a value of close to three-quarters of a billion dollars. This vast amount of ore would make a train of ore cars carrying 50 tons to the car and stretching a distance of 6,060 miles or nearly a quarter

of the circumference of the globe. During this same year the United States Steel Corporation employed a force of more than a quarter of a million and paid out in salaries and wages $347,370,400.

In the Great War steel is paramount. At the memorable battle of Verdun to make good the invincible determination of the men who said, "They shall not pass," required an expenditure of 60,000,000 shells containing 1,800,000 tons of steel. In the first 78 minutes of the big offensive on the Western Front during the spring of 1918, Germany used 650,000 shells, or as many as were employed in the entire Franco-Prussian War of 1871. To maintain one man in France requires 2 tons of shipping or 2,600,000 tons for the first army and this all represents steel construction. Besides, steel ships must make good the Allied loss in the first four years of war of 11,827,572 tons. To build one 8,000-ton ship requires 3,200 tons of steel. In addition millions of tons of naval construction are under way. A railroad program vital to the movement of men, fuel and munitions calls for 100,000 cars and 1,025 locomotives. This item alone will require 1,200,000 tons of steel costing $324,000,000. There is an immediate further need for between 2,000,000 and 3,000,000 steel rails and the mills working 24 hours a day are two years behind their orders. Then, too, there must be steel for motor trucks, tractors, farm machinery, gasoline engines, guns of all descriptions, ammunition in prodigious and inexhaustible quantities and for engineering construction. And as though these stupendous demands were not enough, every day orders for thousands more tons of steel pour in from our Allies across the sea. Upon the steel industry of America rests in largest measure the success of the war and the hope of democracy.

Alloys.—Strange as it may seem the presence in steel of

small quantities of other metals changes to a very remarkable degree the qualities of the steel. Such mixtures of two or more metals melted together are called alloys. Among the common alloys, other than those of steel, are bronze, brass, solder, Babbit metal, lead shot and German silver. All of these alloys have particular properties not possessed by the constituent metals alone, which increase very markedly their range of usefulness. Differences in hardness, melting points, tensile strength, ductility, toughness and electrical resistance are the more common. Some of the effects of other metals on steel are given in the following paragraphs.

Manganese.—In the making of steel it will be remembered that manganese is necessary as a deoxidizer. Steel having from 2½ per cent to 7 per cent of manganese is very brittle, but with more than 7 per cent and up to 18 per cent practically a new metal results possessing great strength, elasticity and hardness. It is used for the jaws of rock crushers, safes, jail bars, etc.

Nickel.—This was one of the first metals to be used in steel and is one of the most valuable in its effects. It increases the tensile strength, ductility and elastic limit. Nickel steel is used for automobile construction and for the moving parts of all kinds of machinery. When containing 30 per cent of nickel the steel can be drawn into wire and this large percentage makes it non-corrosive and therefore well adapted for ships' hawsers, marine cables and other steel construction which is exposed to the action of salt water.

Steel containing 36 per cent of nickel gives an alloy having the lowest known coefficient of expansion, that is, it changes its volume with change of temperature the least of any known metal or alloy. It is used in clock pendu-

lums. If 42 per cent of nickel are present the alloy has the same rate of expansion as glass and is, therefore, useful in sealing the filaments into incandescent lamp bulbs.

Chromium.—Chrome steel is intensely hard. In 1882 chrome steel shells were made that penetrated wrought iron plates 8 inches thick. It is generally used in conjunction with nickel, the chromium giving hardness and the nickel elasticity. Such steel has extensive uses in the manufacture of guns, armor plate and projectiles.

Vanadium.—This is a rare earth metal which has the most powerful effect upon steel for the quantity used of any element. So rare was the metal at first that a pound of it cost $10,000, but there has since been found a large deposit in South America. As little as 2 per cent raises the tensile strength and elastic limit of mild steel by 50 per cent. It is used for the highest classes of tool steel. In high speed steels it trebles and quadruples their cutting qualities. The heat developed does not draw the temper. It also produces what is called "anti-fatigue" steel. Steel which is alternately under tension and compression tends to become brittle or "fatigued," but vanadium resists this tendency. It gives increased strength with diminished weight and is, therefore, used in automobiles, engines, aëroplanes, tractors, etc.

Tungsten.—This metal prevents the softening effect on steel at high temperatures and increases the hardness of steel. Steel having 6 per cent of chromium and 10 per cent of tungsten makes excellent high-speed steel for lathe tools. Tungsten increases the magnetic retentive power of steel and is used in making permanent steel magnets for use in electrical measuring instruments where the strength of field must be uniform from year to year.

Molyndenum has effects similar to that of tungsten.

SIMPLE ALLOYS TO MAKE

Brass.—If you have made the resistance furnace described in the experiments under high temperatures and have available electric current of 110 volts pressure you will have no trouble in making brass. To melt the copper a temperature of 1084° C. will be required, but this furnace will give it.

Place in a fire-clay crucible of suitable size to fit the furnace 70 grams of copper and have at hand 30 grams of zinc. When the copper has melted add the zinc, which will quickly dissolve and mix with the copper.

When the zinc and copper have mixed seize the crucible with tongs and plunge it into a pail of cold water. The brass will very quickly solidify and may be knocked from the crucible.

Bronze.—This may be made in the same way using 75 grams of copper, 15 grams of zinc and 10 grams of tin. Do not add the zinc and tin until the copper is melted.

Solder.—Solder may be easily made in a clay crucible over an ordinary Bunsen burner. Use equal parts by weight of lead and tin.

To run this into sticks make a Plaster of Paris mold. Mix the Plaster of Paris in a pasteboard box-cover and while still soft press into it two or three lead pencils. Into these depressions the molten metal can be poured.

Wood's Metal.—This is an alloy that melts in hot water of about 70° C. Therefore it may be made over a Bunsen burner. Use 15 grams of cadmium, 20 grams of tin, 40 grams of lead and 80 grams of bismuth.

This alloy may be molded as before. On placing a stick of it in hot water it will melt and run about the bottom of the beaker like mercury.

Type Metal.—This is an alloy having the property of expanding on cooling instead of contracting. Therefore in casting type the cooling metal expands, filling the edges out and giving clear-cut definite type.

Melt over a Bunsen burner 75 grams of lead, 20 grams of antimony and 5 grams of tin.

Chapter XIX

GALILEO AND THE TELESCOPE

Thus far we have dealt only with some few of the great inventions which have marked epochs in the material progress of the race. So absorbed we may have become in contemplating these achievements that it is possible our minds have grown to a certain degree earth-bound. In the midst of the daily hubbub that surrounds us, we are apt to forget that this planet and all it contains is but a tiny atom of the universe. Keenly interested in the immediate needs of our material existence, engrossed in a world war of unparalleled magnitude, and deeply conscious of the power for weal or woe of the tremendous forces of nature, we give little thought to the heavens above and the infinite depths of space. But did you ever consider that time and space are without beginning and without end? Can you think of a time when there was no time or imagine a realm where there is no space? If you should take the wings of the morning and fly to the "uttermost parts of the earth," would there not still be space? And did you not ever reflect that every star in the heavens is doubtless the center of a solar system, with worlds like our own? Have we any good reason for doubting that these worlds are peopled with beings engaged in affairs as momentous as our own? This little planet teems with life from the myriad of microscopic organisms in a drop of stagnant water to the mammoth animals of early geologic time. Life is the order of the universe and ours can be but an infinitesimal portion

of it. Only when we thus try to grasp something of the immensity of it all, can we have even an approximate appreciation of the relatively insignificant part which our planet plays in the universe of time and events. Therefore, we may truly say that the genius who perfected an instrument enabling men to push heavenward by millions of miles the frontiers of the known universe and to add to it worlds without end, is the greatest inventor of the ages. Such a genius and such an invention the world has in Galileo and the telescope. Musician, scholar, teacher, physicist, inventor and astronomer, Galileo stands forth to-day, after a lapse of three centuries, as one of the giant intellectual leaders of all time. Breaking away from the traditional bondage of mediæval Europe to Aristotle and the past, Galileo dared to think for himself and blazed the way to the independent thought and freedom of modern science.

Although the first telescope was doubtless made in Holland in 1608, and came about from the accidental placing of one lens over another, Galileo reinvented it at practically the same time and was the first to apply it to an exploration of the mysteries of the stars and planets. His first simple telescope consisted of a lead tube with a double concave eyeglass and a double-convex objectglass. It made objects appear three times nearer and nine times larger. He very quickly made several others, each being of greater power than the preceding, and in a short time had a telescope that brought objects thirty times as close and magnified them nearly a thousand times. With this instrument he made his epoch-making discoveries in astronomy. To his amazement he found that he could count ten times as many stars in the sky as his unaided eye was able to detect. Contrary to the common belief, then, the

stars were not all equidistant from the earth. Those that were brought into view with his telescope must be at greater distances than those revealed with the naked eye. With the first sweep of his telescope across the heavens, he extended the bounds of the universe by millions of miles, and at a single glance destroyed a traditional error of all previous time. Certainly no other observation, even with the most powerful of modern telescopes, ever disclosed as much. It was the beginning of a new knowledge, which was destined to break the fetters of intellectual bondage and enlarge men's minds to a truer conception of the universe of which they are a part.

This astronomer of Padua and Florence next turned his magic tube on the beautiful Milky Way. He showed this belt of silvery light to be made up of myriads of faint stars, too small to be distinguished without optical aid; and at such measureless distances away that they literally seem to rub elbows with each other. Yet this galaxy of stars represents innumerable blazing suns like our own, separated from each other by millions and millions of miles. In these first few days with the telescope, knowledge grew more rapidly than at any time before or since.

A still greater discovery was that of the four moons of Jupiter. Here was a miniature sun with a system of revolving planets. With his telescope, Galileo was able to observe their motion about the great planet. Surely the doctrine of Copernicus as to the central position of the sun and its revolving planets, including the earth, was true. The ancient system of Ptolemy, making the earth the center of the universe, disappeared before the revelations of the telescope. The fame of Galileo and his discoveries spread abroad and great personages crowded to Padua to view the heavens for themselves.

Galileo also discovered that the planet Venus passes through phases just as our moon does. He mistook the rings of Saturn for two small sister planets, but corrected the error later. He studied the surface of the moon and described its lofty mountains and deep volcanic craters. Sun spots were also observed and by noting the interval between the disappearance of a particular sun spot and its reappearance, Galileo was able to prove the rotation of the sun on its axis.

But so intrenched were superstition and error in those dark days of the Inquisition, that instead of being recognized as the greatest scientist and discoverer of his time, Galileo was persecuted by the Roman Church and compelled to recant his belief in the Copernican doctrine. His famous book defending the theory that the earth turns on its axis and not the sun about the earth, was confiscated. The announcement of his recantation was promulgated throughout Europe and his humiliation made as complete as possible. Yet the punishment meted out for those days was exceedingly mild, and he was soon permitted to return to his home. There, amid failing eyesight and eventual blindness, Galileo did much important work in several fields of physical science and, in 1642, died at the age of seventy-eight.

Although his brilliant discoveries in astronomy eclipse everything else he did, his contributions to Physics are the foundation stones of this important science. Every schoolboy knows how, at the leaning tower of Pisa, he disposed of Aristotle's myth about the times of falling bodies, proving that bodies of different weights fall in the same time. Later, in a series of classic experiments, he worked out the exact laws of falling bodies for all subsequent time. He studied the pendulum and discovered one of its funda-

telescopes. A convex lens of short focal length always produces a color fringe owing to the dispersion of light near the edges. This was very troublesome and at first could be overcome only by grinding lenses almost flat and therefore of great focal length. This necessitated very long and unwieldly telescopes awkward to manipulate and requiring a prodigious amount of time and patience in their use. Achromatic lenses were later devised to overcome this difficulty, but before this time, Newton, despairing of success with the refracting type, built the first great reflector.

The largest refracting telescope in the world is the 40-inch telescope at the Yerkes Observatory of the University of Chicago, Williams Bay, Wisconsin. The 36-inch refractor at the Lick Observatory, Mount Hamilton, California, comes second. These and a number of other famous refractors were designed and constructed by the American firm of Warner and Swasey, at Cleveland, Ohio. This firm has also recently constructed the world's largest reflecting telescope for the Dominion Astronomical Observatory, Victoria, Canada. The reflecting mirror for this monster telescope is 72 inches in diameter and weighs 2¼ tons. It was made by John A. Brashear, of Pittsburgh, Pennsylvania, one of the world's greatest opticians. The telescope as a whole weighs 55 tons and rests upon massive piers of reinforced concrete. Another American firm that has done conspicuous work in the difficult art of making refracting telescopes is that of Alvan Clark and Sons. Nearly all of the great refractors have been made in America.

Nothing has contributed so much to the broadening of men's minds as the revelations of the telescope. It has done more than any other invention to destroy ignorance

and superstition and to enable men to understand and interpret the great laws of the universe. And since we find the universe and its laws intelligible, must it not follow that back of them are thought and purpose and intelligence? No intelligible creation ever proceeded from a nonintelligent source. Every invention described in these pages is the product of thought. By means of suitable mechanisms the purpose in the mind of the inventor is materialized. If there is no purpose, there can be no invention. Every material creation must first exist as a mental creation; and what a machine is to an inventor, so is the universe to the Creator. If this universe did not represent thought and purpose, then Nature would be an insoluble riddle. Its forces would be meaningless and inexplicable. It would not be amenable to human intelligence and there would be no medium of mutual communication. The very fact that we can understand nature and her laws compels us to affirm personality back of them. From this conclusion we cannot escape. No one can look into the measureless distances of space and contemplate the infinite universe of perfect law, without irresistibly feeling that back of it all stands the Supreme Inventor of the Ages.

EXPERIMENTS WITH MIRRORS AND LENSES

1. *Concave Mirror.*—Place a concave mirror of about 2½ inches diameter and 6 inches focus on a table and resting against a vertical support. Place a lighted candle at more than twice the focal length from the mirror and a little to one side of a perpendicular line to its center. Move a white cardboard screen back and forth in front of the mirror, and at a distance of more than once and less than

twice the focal length an inverted real image, smaller than the object, will be obtained.

Standing back some distance from the mirror, place the eye in line with the image and an inverted candle will seem to be suspended in space at the position where the screen was held.

Repeat the above experiments, moving the candle nearer to the mirror. You will find a point—twice the focal length—where object and image will be equidistant from the mirror and of the same size. When the candle is placed within this distance, the image moves farther away and becomes magnified.

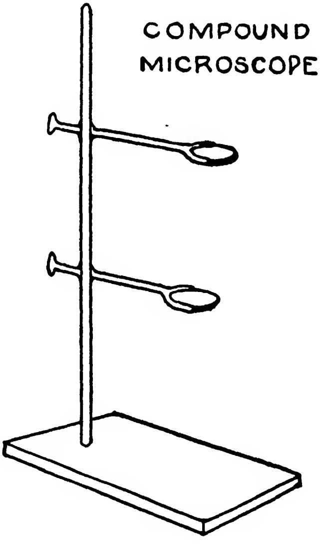


FIG. 103.

2. *Virtual Image with Convex Lens.*—Using a double convex lens of 4 inches focus, place it at a distance of less than the focal length from your hand and look through it. A magnified image appears. This is a virtual image and the sort of an image obtained with the eyepiece of a telescope or compound microscope.

3. *Real Image with a Convex Lens.*—Bend wire so as to form a lens holder and mount a double convex lens of about 12 or 14 inches focus on a yardstick. Hold the lens and stick so as to get the view from an open window and behind the lens move back and forth a white cardboard screen. A distinct inverted image of some distant object will be

obtained. This is a real image obtained by placing the screen at the position where the rays of light from the object are brought to focus by the lens.

4. *Real Images of a Candle.*—Perform the same experiments with the lens as you did with the concave mirror, and very similar results will be obtained. In this case, however, object and image will be on opposite sides of the lens.

5. *A Compound Microscope.*—Clamp two lenses of about 2 or 3 inches focal length to an upright support, as shown in Fig. 103. Place a piece of white paper with a short arrow marked on it for object below the objective. Mount the

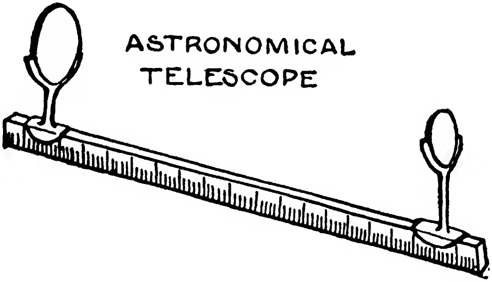


FIG. 104.

objective so that it will be more than once but less than twice the focal length from the object. Now move the eyepiece up and down until a distinct magnified image appears. The centers of both lenses must be in the same straight line.

6. *The Astronomical Telescope.*—For objective, mount on a yardstick a double convex lens of about 14 inches focal length and an eyepiece of not over 4 inches. Place the centers of the two lenses exactly on a line and at a distance apart equal to the sum of their focal lengths.

With a little adjustment of the eyepiece a distinct, inverted and magnified image of distant objects will be obtained.

If desired, these lenses may be fitted into the ends of paper tubes blackened on the inside and telescoping into each other.

A telescope of sufficient power for simple observations of the moon and several of the planets may be made by mounting in similar manner round spectacle lenses, numbers 5 and 30. Number 5 will be the eyepiece and number 30 the objective.

The focal length of a lens may be determined by measuring the distance between the lens and the position of the image of some distant object.

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